US Army Corps
of Engineers

FINAL REPORT

Seattle Public
Utilities

PIT Tagging of Juvenile Salmon Smolts in the Lake Washington Basin: Fourth Year (2003) Pilot Study Results and Synopsis of 2000-2003 Findings

Lake Washington General Ecosystem Restoration General Investigation Study

U.S. Army Corps of Engineers, Seattle District

Contract No. DACW57-00-D-0003

R2 Resource Consultants, Inc.

January 18, 2005

PIT Tagging of Juvenile Salmon Smolts in the Lake Washington Basin: Fourth Year (2003) Pilot Study Results and Synopsis of 2000-2003 Findings

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January 18, 2005

Funding and resources provided by:

- U.S. Army Corps of Engineers,
- Seattle Public Utilities,
- King County
- King Conservation District
- Washington Department of Fish and Wildlife

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ABSTRACT

This study continued the evaluation of Passive Integrated Transponder (PIT) tag technology for monitoring smolt migration and survival characteristics as they pass through the Lake Washington and Lake Washington Ship Canal (LWSC) system, including the Hiram M. Chittenden Locks (Locks). This was the fourth consecutive year of study, conducted as part of the Lake Washington General Investigation Study, and was partially funded through a King Conservation District grant. Four smolt flumes and PIT tag detection devices (tunnel readers) were again installed over the spillway dam of the Locks to monitor outmigration during the spring of 2003. Juvenile Chinook, coho, and sockeye salmon were captured, tagged and released variously in the lower reaches of the Cedar River and Bear Creek, in the Sammamish River near Marymoor Park and Kenmore, and at various locations in Lake Washington and the LWSC. In addition, Issaquah Hatchery Chinook were tagged and released onsite at the Sammamish River study areas, to supplement release numbers when catch rates were low. A few steelhead juveniles were also captured, tagged, and released. Hatchery-reared Chinook were tagged, held, and released at the Issaquah Creek Hatchery. Calibration tests were performed using tagged hatchery Chinook juveniles to evaluate the detection efficiency of the tunnel readers.

A significant problem occurred in 2003 compared with previous years in that surface water temperatures warmed early in the LWSC and Lake Washington, resulting in reduced passage rates at the flumes earlier in the season. In addition, inflows were the lowest on record, necessitating the use of fewer flumes and an earlier shutdown than in previous years. Similar issues as previous years included structural features of the flumes reducing the detection efficiency of the tunnel readers, and the absence of complete coverage of PIT tagged fish passing the Locks through other routes.

Nevertheless, the data again provided valuable, detailed biological information for a fourth, consecutive year on migration and passage behavior of salmon smolts originating from different parts of the Lake Washington basin and transitioning to adult life in saltwater. The data included seasonal and diurnal migration and passage timing, some passage routes through the Locks, and further evidence of repeat cycling through the Locks. Passage rates were compared with flume discharge with the goal of determining optimal water allocation to the flumes. The data were also used to evaluate survival for different portions of the migration route, although the precision of the estimates was poor because of variable detection rates at the Locks on both a daily and seasonal basis, and the small number of release locations. Further testing led to a refinement of a shoreline affinity hypothesis developed in 2002, in that it was deduced that fish generally appear to exhibit shoreline affinity in the lake and LWSC, except in the Montlake and Fremont cuts and in the vicinity of the Locks, where the fish appear to mix thoroughly across the width of the LWSC. A small number of Chinook and coho juveniles tagged in 2002 came through the Locks in 2003, as did one Cedar River Chinook tagged in 2001. Water temperature in the LWSC and lunar phase appeared to influence outmigration characteristics. This information can be used for shaping spill timing and volume requirements at the Locks, and for evaluating causal mechanisms of decline. Study implications and improvements are suggested. A synopsis is also presented of salient results for all four study years.

ACKNOWLEDGEMENTS

This document reports the results of studies conducted jointly by Seattle Public Utilities, King County Metro and the U.S. Army Corps of Engineers (USACE), Seattle District as part of the Lake Washington General Investigation (LWGI) Study. Project managers for the respective funding institutions are: Linda Smith, Project Manager, LWGI Section 1135 Study, and Fred Goetz and Chuck Ebel, PIT Tag Study Project Managers, USACE; Doug Houck, King County/Metro; and Keith Kurko, Melinda Jones, Julie Hall, and Gail Arnold, Seattle Public Utilities. Partial funding was provided through a King Conservation District Watershed Forum and Municipality Noncompetitive Grant to support collaborative tagging studies conducted by Parametrix, Inc. for Seattle Public Utilities. A large number of persons contributed significantly to study design and implementation in 2003, including: Kurt Fresh, NOAA Fisheries; Bob Pfeifer, Parametrix (later moved to WDFW and who also transported hatchery test fish from the Issaquah Creek Hatchery to the King County/Metro Environmental Laboratory); Francis Sweeney, and Gary Yoshida provided holding facilities and took care of fish at the King County-Metro Environmental Laboratory; Dave Seiler, WDFW, team leader for the multi-year study of smolt trapping in Lake Washington tributaries; Scott McCutcheon of Biomark, Inc., and Jim Sadler, USACE provided assistance with tagging fish or troubleshooting PIT tag tagging and detection equipment; Lindsey Fleischer, WDFW, was responsible for tagging fish caught in the tributary screw traps; Bob Pfeifer, Pete Lawson, and Bill LaVoie, Parametrix, set up and conducted lake tagging activities; Kyle Bouchard and Peter Johnson, BAE Systems/USACE Waterways Experiment Station, provided tunnel reader data on a daily basis, were on site to monitor the equipment, and provided general support at the Locks; and John Post and Bill Livermore, USACE, were responsible for installation and implementation of smolt flume facilities and provided assistance in other aspects of the study.

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1. INTRODUCTION

The Hiram M. Chittenden Locks (Locks; also known as the Ballard Locks) were constructed by the Seattle District, U.S. Army Corps of Engineers (USACE) as part of the Lake Washington Ship Canal (LWSC) project between 1911 and 1916 to provide for navigation between Lake Washington and Puget Sound (Figure 1-1). The LWSC is approximately 14 km (8.6 miles) long and lies entirely within the boundaries of the city of Seattle. The project was authorized by Public Law 61-264, River and Harbor Act of 25 June 1910, in the First Session of the 60th Congress in accordance with a plan set forth in House Document 953. The Montlake Cut, which extends between Lake Washington and Lake Union, was the final link in the route and was completed in 1917. Official dedication of the Locks project occurred on July 4, 1917. Other concurrent, related activities included closure of the historic outflow of Lake Washington into the Black River in 1912 and concomitant rerouting of the Cedar River into the lake for flood control (Hanson 1957). Although the Locks have since undergone several structural modifications and improvements including construction of a saltwater intrusion barrier in 1966 and a new fish ladder in 1976, the entire LWSC project has effectively influenced anadromous fish passage and migration from the time it was constructed through to the present day.

The Washington Department of Fish and Wildlife (WFDW) and Muckleshoot Indian Tribe (MIT) initiated field research in 1994, in cooperation with the Environmental Resources Section of the Seattle District, regarding the effects of operation of the Locks on the survival and general well-being of anadromous salmonids utilizing the Lake Washington watershed for various parts of their life-cycle. Issues raised in the studies have included successful downstream passage of juvenile and adult outmigrants, loss of estuarine habitat and the effects of a relatively sudden freshwater-saltwater transition, intrusion of saltwater into Lake Washington, and upstream passage of adult migrants. These and other concerns are particularly germane now in light of recent listings under the federal Endangered Species Act (ESA) of Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*; listed in 1999 as “threatened”; 64 FR 14308) and bull trout (*Salvelinus confluentus*; listed in 1999 as “threatened”; 64 FR 58910), and potential listing of coho salmon (*O. kisutch*). It is important that the influence of the LWSC project on salmonid survival and health be fully understood so that appropriate measures can be developed and enacted at the locks that minimize or eliminate adverse effects. In addition, it is important that migration behavior and survival be better understood in the Lake Washington basin to maximize effectiveness of restoration efforts and projects. This document details the results from a fourth year of a study of migration and passage behavior and survival using Passive Integrated Transponder (PIT) tag technology (Prentice et al. 1990a,b,c). The study builds on three years

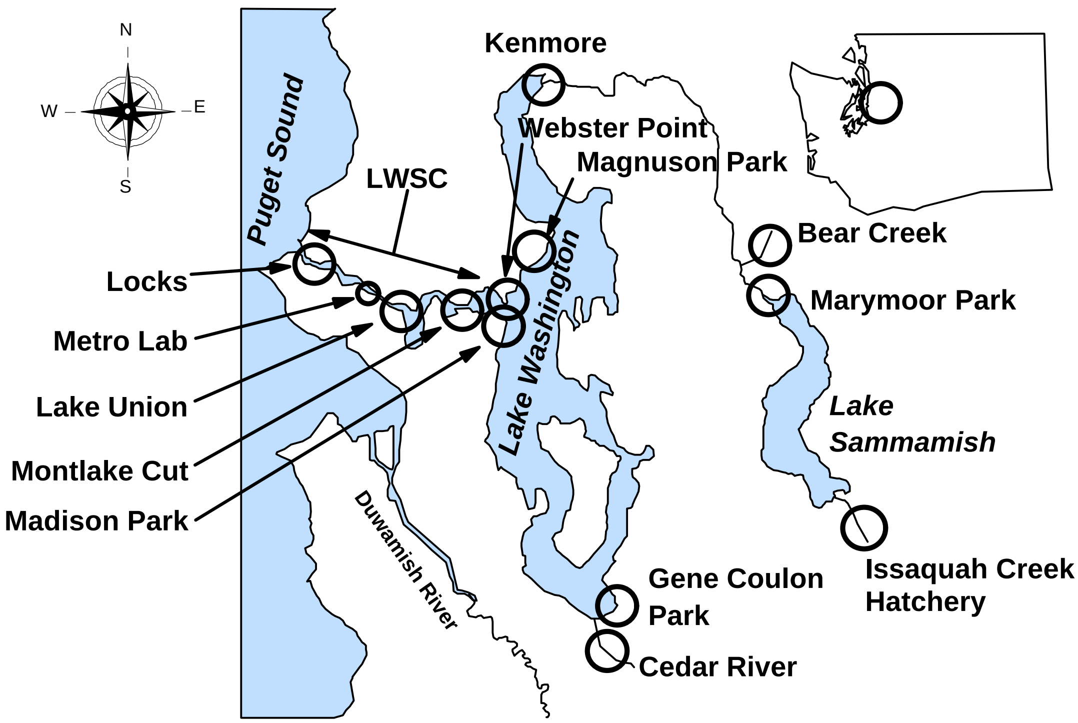

Figure 1-1. Locations of the Lake Washington Ship Canal (LWSC), Hiram M. Chittenden Locks, and PIT-tagged fish releases in the Lake Washington.

of work conducted as part of the greater Lake Washington General Ecosystem Restoration General Investigation (LWGI) Study conducted by the Seattle District of the USACE.

1.1 PHYSICAL LAYOUT, FEATURES, AND OPERATION OF THE LOCKS

The Locks consist of a large and small lock on the north side, a fish ladder on the south side, and a 71.6 m (235') long concrete gravity spillway dam extending between the small lock and the ladder (Figure 1-2). There is also a saltwater return system that consists of a drain leading to below the spillway dam and a pipe that runs along the bottom of the LWSC to the fish ladder. The pipe discharge is distributed to a number of steps where it mixes with the freshwater entering the head of the ladder.

The large lock is 24.4 m (80') wide and can accommodate ships with drafts up to 9.1 m (30'). It consists of three operating gates that divide the lock into two chambers, two 4.3 m (14') high by 2.6 m (8.5') wide culverts that run longitudinally along each side of the lock and pass lake water

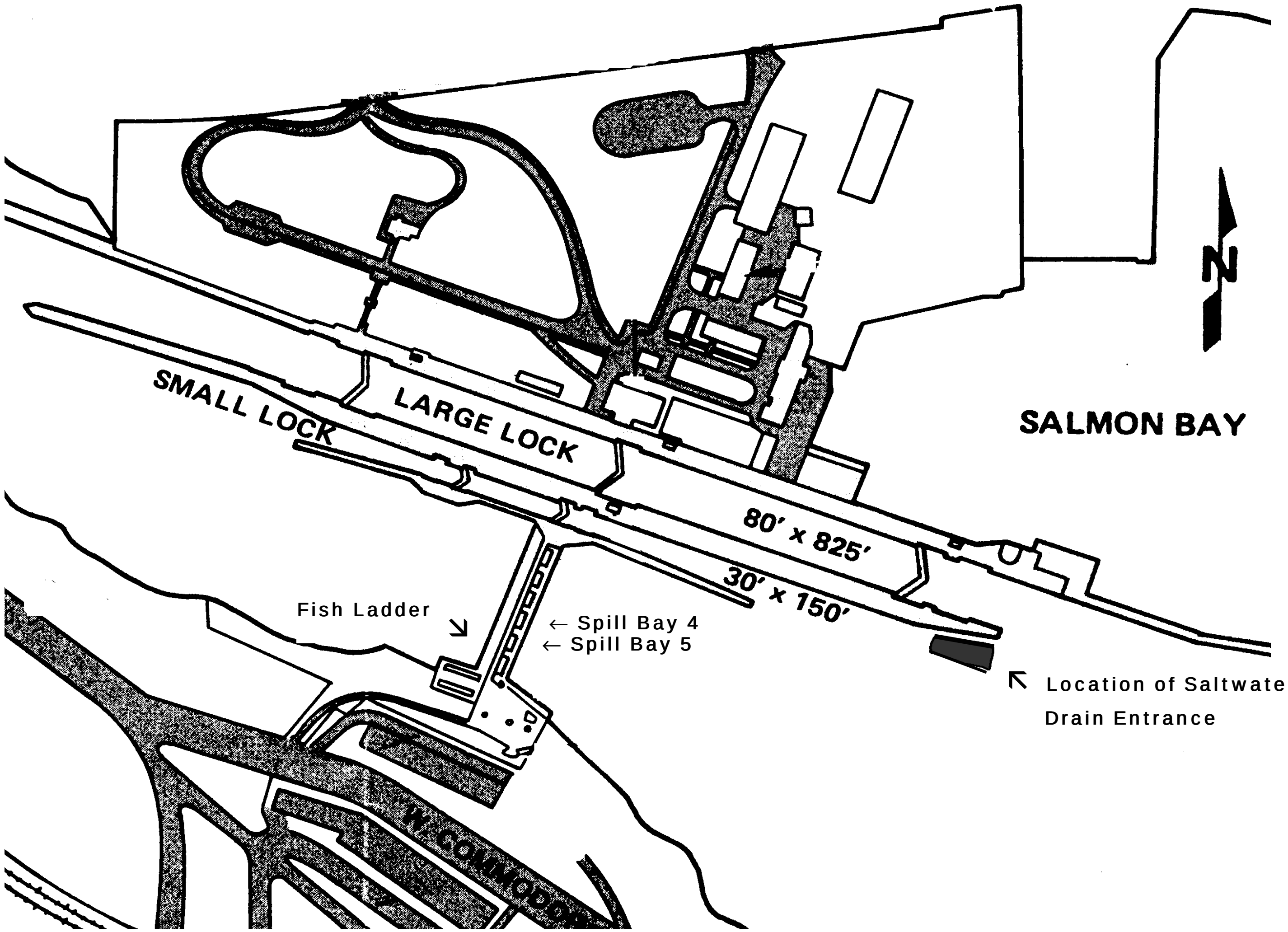

Figure 1-2. Plan view of the Hiram M. Chittenden Locks showing major structural features and location of tunnel readers in spill bays 4 and 5.

into the lock to fill it, filling valves, and dewatering facilities. During normal operations, either one or both chambers are used depending on the size and number of ships passing through the facility. The valves can be used to vary the rate at which the lock is filled. A saltwater barrier is located at the upstream end of the lock and can be raised to reduce the volume of saltwater intruding into the LWSC when the upper gate is opened. Relatively strong density currents can occur within the lock when the gate is opened, as surface freshwater enters the lock to replace the denser saltwater flowing out into the LWSC.

The small lock is 9.1 m (30') wide and can accommodate smaller boats with drafts up to 4.9 m (16'). It consists of two operating gates, two 1.8 m (6') high by 2.6 m (8.5') wide culverts that run longitudinally along each side of the lock and pass lake water into the lock to fill it, filling valves, and dewatering facilities. The valves can be used to vary the rate at which the lock is filled.

Saltwater intrusion is an important concern, particularly with respect to managing water quality of Lake Washington and Lake Union, because of the concern that the resulting density stratification and water quality attributes of the lakes could transform their deeper areas into sterile, anaerobic waters. The Washington Department of Ecology has correspondingly set water quality standards, where the salinity in the LWSC at the University Bridge may not exceed 1 $^{o}/_{oo}$ (parts per thousand, ppt) at any point in the water column. The Locks are therefore managed to minimize intrusion as much as possible, which occurs with each lockage when a denser, more saline layer flows upstream under the less dense freshwater in the form of a density (or, gravity) current. The large lock is associated with approximately 25 times more saltwater intruding per lockage than the small lock, but the small lock is conversely used more frequently. A hinged barrier on the large lock bottom partly retards saltwater intrusion, but the main line of defense is the saltwater drain located immediately upstream. The saltwater drain has a discharge capacity of 300 cfs and returns water downstream, including through the fish ladder.

The spillway dam consists of six bays that are numbered sequentially as numbers 1 through 6, from North to South. Each bay is 9.8 m (32') wide and controlled by a 3.8 m (12.5') radius tainter gate that is driven by an independent electric motor. The spillway has a design head of 2.3 m (7.4'), a crest elevation of 4.2 m (13.75'), an ogee shape, and is capable of discharging up to 515 m^3/s (18,200 cfs) at the maximum regulated Lake Washington elevation of 6.7 m (22'). Beginning in May 2000, four seasonal smolt passage flumes (smolt flumes) have been installed in bays 4 and 5 with the goal of passing downstream migrating juvenile salmonids by the Locks (the flumes have been installed in April in each following year). These flumes replaced a prototype 'smolt slide' that was installed initially in 1995 for the same purpose of passing smolts downstream of the Locks.

The Locks regulate the elevation of the water surface of Salmon Bay, Lake Union, and Lake Washington. Project authorization documents specify the normal operating levels to be between 6.1 m (20') and 6.7 m (22') above the USACE Project Datum. The Project Datum, established on 1 January 1919, is 2.08 m (6.82') below the National Geodetic Vertical Datum (NGVD) and 0.17 m (0.57') below the Seattle mean lower low water (MLLW) elevation. In constructing the LWSC project, the level of Lake Washington was lowered about 2.7 m (9') from its historic elevation. The storage between the 6.1 m and 6.7 m levels has been used historically to augment LWSC inflows for use in operating the Locks, the saltwater return system, and the fish ladder facility. More recently, the storage is also used to provide flows to the smolt flumes during the spring outmigration period.

There are four seasonal periods of operation: the winter holding period (low pool), the spring refill period, the summer conservation holding period (full pool), and the fall drawdown period. The lake elevation is maintained at the minimum operating level (6.1 m) during winter months to allow for maintenance on docks, walls, etc. by businesses and lakeside residents, minimize wave and erosion damage during winter storms, and provide storage space for high inflows during flood events. The spring refill period begins February 15 and continues until generally the first week in May when the lake reaches 6.66 m (21.85'), which is slightly less than the full pool level (6.7 m; levels can reach this depending on water availability). The spillway gates (and also now the flumes when appropriate) are operated to keep the lake elevation near its maximum authorized normal level of 6.7 m. The upper limit is dictated by physical design restrictions of the spillway gates and requirements of lake-associated infrastructure. Water demands of the Locks, the saltwater drain, the fish ladder, and the flumes result in the lake elevation gradually lowering, beginning in late June to late July depending on water availability. The Water Conservation Plan that is in effect at the Locks attempts to maintain lake levels at or above the 6.1 m level as much as possible (70% historic reliability level). It is not always possible, however, to maintain this elevation during abnormally low water years and when higher than usual saltwater intrusion associated with lock openings requires additional flushing.

1.2 CONTEXT AND PURPOSE OF THE PIT TAG STUDY

The 2003 PIT tag study is part of the greater LWGI study, which was initiated in May 1999. The LWGI study is a USACE project with the City of Seattle (Seattle Public Utilities) and King

County as local sponsors. Additional funding for the 2003 PIT tag study was provided by King Conservation District as requested by the WRIA 8 Technical Committee and the City of Seattle.

The purpose of the LWGI study is to develop a set of ecosystem restoration projects to provide benefits primarily to salmon in the Lake Washington basin. This includes evaluation of various projects that may contribute to restoration of ecological processes or functions within the Lake Washington basin, including projects that will improve passage of juvenile and adult salmon through the Locks. The LWGI study has included salmon studies at the Locks, in the Ship Canal, and in Lakes Washington and Sammamish and their tributaries since 2000. Activities have entailed studies that improve knowledge and understanding of the life history and ecology of native fish in the Lake Washington basin. Relevant projects have included making fish passage improvements at the Locks and in the LWSC, and implementing water conservation measures to provide additional water for fish passage through the Locks. PIT tagging studies help address data needs associated with better understanding of salmon migration in the greater Lake Washington basin and relative survival of out-migrating juvenile salmon, and have been conducted every year of the GI Study. In addition, PIT tag monitoring of juveniles has complemented post-flume construction monitoring performed as part of the Lake Washington Ship Canal Smolt Passage, Section 1135 Restoration Project (USACE 1999).

Results presented in this report address the following overall objectives for PIT tagging during year 4 of the LWGI Study:

- Continue documentation of the migration timing characteristics of naturally and hatchery reared salmon in the Lake Washington basin with a primary emphasis on Chinook salmon;
- Further focus the evaluation of mark and recapture of PIT-tagged fish as a means to estimate survival of Chinook juveniles within specific segments of their migratory pathway, including conducting controlled fish releases above the Locks to assess PIT tag detection efficiency in the smolt flumes; and
- Synthesize results of all years of PIT tagging in WRIA 8.

In addressing the above objectives, the resulting data were intended for use in evaluating alternative operations and structural measures at the Locks and other restoration measures in the Lake Washington system. An additional goal in 2003 was to increase the resolution of sampling such that more release locations could be added to the overall PIT tag studies, thereby facilitating analyses of survivals along shorter segments of the outmigration route and to further differentiate where along the migration route survival was lowest. From this, it was hoped that sources of mortality could be elucidated for subsequent use in determining more definitively where in the system restoration-related activities, and what water management alternatives, would be most effective.

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2. METHODS

In addition to further evaluating the feasibility of PIT tagging in the Lake Washington system, this study was also designed to yield first-order estimates of survival over various portions of the migration route and details about migration characteristics related to factors within and outside of the control of water management operations at the Locks. The overall study design involved tagging and release of natural and hatchery origin juvenile Chinook salmon at various locations in the watershed, and detecting them at the Locks and downstream. Study design and methods are described below.

2.1 PIT TAG TECHNOLOGY

PIT tags are small, unobtrusive electronic devices that are implanted in the abdominal cavity of fish. The tags used in this study were 134.2 kHz Destron-Fearing TX1400BE, 14 character tags. The tags do not appear to influence fish behavior or survival significantly when inserted properly (Prentice et al. 1990c). Delayed tagging mortalities generally do not exceed 1% based on extensive experience in the Columbia River (Muir et al., 2001a,b; Dare 2003). The tags consist of an antenna coil of coated copper wire that is connected to an integrated circuit chip, all encased in a glass tube that is approximately 12 mm long and 2.1 mm in diameter (Figure 2-1). The device works on the principle of induction of current in a coil as it passes through an electromagnetic field. As the tag passes through the field created by a detection device, the current that is induced in the coil powers the chip, which subsequently transmits a unique tag identification number code through the coil. The tag signal is received by a coil loop of the detection device and is decoded. Each PIT tag in this study had 10 unique characters that distinguished it from approximately 34×10^9 other possible code combinations (Prentice et al. 1990a, b, c).

The distance at which a PIT tag may be detected is relatively short because of power generation and dissipation concerns in a water medium. Consequently, the fish must either be made to pass through the coil of a detection apparatus that is fixed in position at a structure where passage can be controlled, or the tagged fish must be captured in the field and held near a portable ('hand-held') detector. In this study, four fixed detectors ('tunnel readers') were custom fabricated and installed in spillway bays 4 and 5 at the Locks, and hand-held detectors were used in the field for detecting tagged fish that were caught during various seining operations.

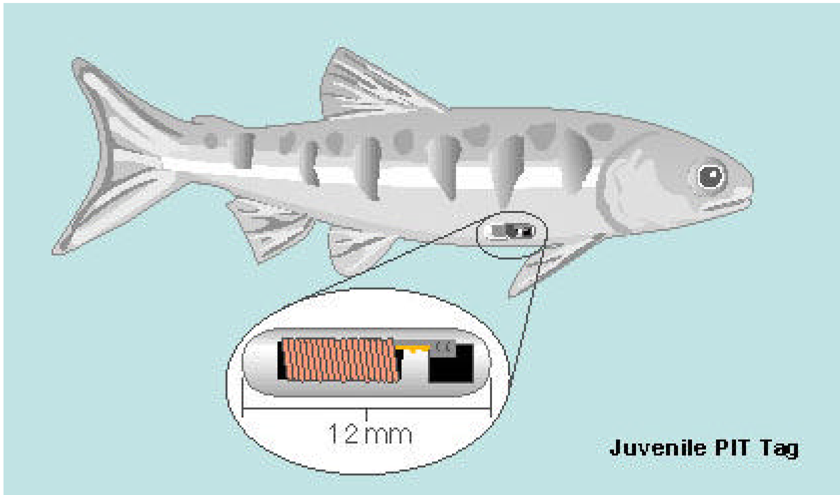

Figure 2-1. Schematic of a Passive Integrated Transponder (PIT) tag inside a juvenile salmonid.

2.2 INSTALLATION AND MONITORING OF TUNNEL READERS AT THE LOCKS

Spillway bays 4 and 5 were converted into smolt passage facilities by raising the radial gates and installing bulkheads with adjustable gates that controlled free surface water flow into four flumes, two located in each bay. Flumes were numbered according to spillway bay (4 or 5) and entrance size (A = 0.69 m (2.25') wide entrance; B = 1.8 m (6') wide entrance; C = 1.2 m (4') wide entrance). Flume number assignments were, from north to south, 4A, 4B, 5C, and 5B (or alternatively, numbers 1 through 4, respectively). Each flume was cantilevered out over the spillway face and led to a tunnel reader that was attached to its end (Figure 2-2). However, this configuration was associated with structural vibration problems in 2000 that led to reduced detection efficiencies. In response, the flumes were "stiffened" at the beginning of the 2001 study by using steel rods attached at one end to the flume and at the other end to the concrete spillway. Tension was applied to the rods by means of turn-buckles, which were adjusted until structural vibrations were minimized. Unfortunately, some residual vibrations remained that could not be corrected, and that were apparently associated with the open channel flow contraction and associated supercritical flow standing waves occurring in the flumes. This was a greater problem in the two large flumes (4B and 5B). At certain lake levels, standing waves appeared to move slowly through the readers, as manifest by pulses in the outfall water.

The sidewalls and floor of each flume were constructed of stainless steel screen so that some of the water entering the flume passed through the screens, thereby reducing the amount of water entering the tunnel reader. A larger flow rate was needed at the entrance of the flume than could be passed through the tunnel reader to ensure (i) large attraction flows and (ii) water velocities that significantly exceeded the swimming capacity of the tagged fish as they passed through the flume and reader. Entrance flows to each flume at normal operating capacity were 1.4, 3.7, 2.5, and 3.7 m^3/s (50, 130, 90, and 130 cfs) for Flumes 4A, 4B, 5C, and 5B, respectively. Outflows were approximately 0.34, 0.42, 0.40, and 0.42 m^3/s (12, 15, 14, and 15 cfs), respectively. The difference between inflow and outflow is the amount that passed through the screen walls of the flumes, and was designed to facilitate visual monitoring or capture of smolts passing through the flumes.

A flow-related operational problem occurred irregularly when the lake level was relatively high, and involved periodic over-topping of the flumes. The amount of water spilling over was relatively small, and occurred in pulses that may have been associated with the transient standing waves. However, a fish stick would occasionally be ejected from the flume in this manner during reader detection efficiency testing. Observation of the flumes and fish swimming behavior did not indicate fish were being ejected, suggesting that few if any fish bypassed the tunnel reader when the flume overtopped. Because the number of PIT tagged fish was small relative to the total number of fish passing the Locks, it is likely that if tagged fish were ejected, the number would have been negligible.

The tunnel readers used were Destron-Fearing 134.2 kHz PIT tag monitors. Each tunnel reader contained two independent sets of coil and electronic components that detected and recorded PIT tags separately as they passed through the reader (Figure 2-3). The tag numbers were stored on two computers (one main, one backup) located in the fish ladder maintenance room. The Windows™-based MINIMON computer program was used. This program automatically created a new file each day and stored a complete record of detections and self-testing logs for each coil. Relevant data included PIT tag numbers, identification of the coil that detected the tag, and the time and date of detection. Data were retrieved from the computers on almost a daily basis. The PIT tag information was extracted using a Fortran program written to filter out other information and pre-process the data prior to QA/QC checking and subsequent data analyses.

Figure 2-2. The smolt flumes and PIT tag funnel readers, in position and operating at the Locks during spring 2000. Flumes are numbered, from left to right (and north to south), 4A, 4B, 5C, and 5B. View is from walkway next to fish ladder.

Figure 2-3. A PIT tag tunnel reader, prior to its installation at the Locks. Note the two reader coil units. Flow is from left to right through the pipe. The mounting bolts on the left end are for attaching the reader to the flume.

As in previous years, tunnel reader electronics would go out of phase from time to time, but the exact time and duration could not be determined because testing was generally limited in frequency to roughly a weekly basis. This phase shift would result in reduced detection efficiency. For example, the coils of the tunnel reader in Flume 5B appeared to have gone out of phase gradually during the last two weeks of May, 2003, after which the electronics were re-tuned by J. Sadler to maximize potential detection efficiency; the electronics were checked periodically by J. Sadler. It is not known the extent to which these problems affected the total number of tag detections evaluated in this study. Calibration testing results are presented in Chapter 3, from which daily detection efficiencies were estimated.

2.3 TAGGING, HOLDING, AND RELEASE OF FISH

Juveniles of four salmonid species were tagged: Chinook salmon, coho salmon, sockeye salmon, and steelhead trout. PIT tagging was conducted for five main study groups (see Section 3.1 for numbers tagged and released):

- Calibration groups of Issaquah Hatchery Chinook salmon were tagged and held at the King County/Metro (Metro) Environmental Laboratory for later release into the smolt slides. These fish were used to determine the detection efficiency of the tunnel readers installed at the Locks during the smolt outmigration season;
- An experimental group of Chinook salmon were tagged and later released at the Issaquah Hatchery to provide another year of data for this stream, for identifying longer term trends;
- Naturally-spawned Chinook salmon, coho salmon, and an occasional steelhead or sockeye offspring were caught by WDFW personnel, tagged, and released at two different locations in the Lake Washington watershed to evaluate passage characteristics of fish using the smolt flumes:
  - Bear Creek (at the WDFW juvenile outmigrant smolt screwtrap)
  - Cedar River (at the WDFW juvenile outmigrant smolt screwtrap)
- Groups of natural and hatchery origin Chinook salmon, coho salmon, and sockeye salmon were tagged and released at different locations in the Lake Washington basin to evaluate migration rates and survival over different segments of the migration route to a finer resolution than in previous years. The tagging work was conducted by Parametrix, Inc. staff under contract to Seattle Public Utilities, in a collaborative effort with the USACE. Hatchery-raised Chinook salmon were transported from Issaquah Hatchery,

tagged, and released on some dates when catch rates were low. Release locations included in the Sammamish River near the exit of Lake Sammamish (Marymoor Park site), in Lake Washington at four sites (Kenmore, Magnuson Park, Webster Point, Madison Park), and in the LWSC at four sites (Gasworks and Metro Lab locations, south and north shores for evaluating shoreline affinity and the proportion using the flumes). A report summarizing those tagging activities is presented in Appendix A;

- A single opportunistic sample of Chinook salmon was also tagged and released at Gene Coulon Park, in a collaborative effort between WDFW and the US Fish and Wildlife Service;

All tagging was conducted using methods described by Prentice et al. (1990c). C.S. McCutcheon (Biomark Inc.), C. Ebel (USACE), and L. Fleischer (WDFW) tagged hatchery Chinook salmon at the Issaquah Creek Hatchery and at the Metro Lab. L. Fleischer also tagged fish caught at the Bear Creek and Cedar River screwtraps and at Gene Coulon Park. Bill LaVoie tagged fish for Parametrix.

Tagging operations involved insertion into the abdominal cavity using a large bore syringe, and measuring the length of the fish on a custom digitizing pad. Data for individual fish were collected using one or two data collection stations (Biomark brand) equipped with Pacific States Marine Fisheries Commission (PSMFC) software (PITTAG2.EXE). The PIT tag number and fish length data were scanned into a PIT Tag Information System (PTAGIS) format file for submission to the PSMFC database maintained in Portland, Oregon (the files were edited for mortalities and tag loss before submission). After tagging, the needles on the syringes were disinfected in an ethyl alcohol bath for a minimum of 10 minutes before being reloaded and reused.

Letter reports from WDFW and Parametrix detailing 2003 tagging activities and mortalities are presented in Appendix A.

Releases of PIT tagged fish were designed to address questions regarding (i) differential survival rates along portions of the migration route, and (ii) the nature and variation of outmigration characteristics in the Lake Washington watershed. Release locations are depicted in Figure 1-1. More sites were sampled in Lake Washington proper than in previous years in an effort to increase the resolution of segment survival and migration rate estimates. A goal of this increased resolution was to provide information that could be useful for optimizing or coordinating future habitat restoration and predator control efforts within the lake.

2.3.1 Issaquah Hatchery Chinook

A total of 1000 age 0+ Chinook salmon originating from the Issaquah Creek hatchery were tagged on location on April 15, 2003. Of these, only three fish died during tagging, and another five died during holding; 992 fish were ultimately released with other Chinook smolts on May 19, 2003 into Issaquah Creek. The tagged fish were held in the outdoor raceways with other non-tagged fish. Tagging was done during the same period that the fish were being fin-clipped by hatchery personnel. Fish were transported in buckets to two tagging stations, anaesthetized, tagged, and released into a separate cage placed within one of the raceways.

The fish were relatively small (length generally between 55-75 mm) and thus difficult to tag. Water temperatures were relatively warm compared with previous years, on the order of 9.5ºC. In contrast with previous years, however, no tags were known to have been shed during the holding period, as no tags were recovered from the holding cage or raceway using a powerful magnet. This probably reflects the fact that feeding was stopped three days prior to tagging and was not resumed until three days after tagging. The fish therefore did not have full stomachs that would promote tag ejection prior to the tagging wound healing. In addition, water temperatures were more optimal for rapid tag wound healing, and only fish that appeared to be in prime condition were tagged (C. Ebel, USACE, personal communication). The raceway was not checked after it had been drained, however, so the possibility exists that an unknown number of tags may have been shed. The number is likely to have been very small, if non-zero.

2.3.2 Metro Laboratory Chinook

Chinook from the Issaquah Hatchery were held at the Metro Laboratory for purposes of periodic calibration testing in the flumes. A group of 2,050 Chinook juveniles were transported from the Issaquah Creek Hatchery to the Metro Laboratory in late April 2003. Of these, 1751 were tagged at the hatchery on April 16, 2003. The fish were anaesthetized prior to tagging using MS-222 to reduce stress and injury during tagging. Water temperature was around 9.5ºC. Fish were removed using standard dip nets and groups of approximately 60 fish were placed in 19 liter (5 gallon) buckets and carried to the tagging tables. Small groups of approximately 20 fish were then dipped and anaesthetized prior to tagging. The fish were held at the hatchery for recovery and moved to the Laboratory on April 18, 2003.

A group of 299 Chinook juveniles were moved from the Issaquah Hatchery on April 14, 2003, and tagged with newer, improved (“super”) tags at the Metro Laboratory on April 16, 2003. Super tags have a larger ferrite core and thus larger coil area which increases the sensitivity of the tag. These fish were tagged for the purpose of comparing detection efficiency of the tags that have been used to date in the GI study with the "supertags," to determine if future studies should use the new tags instead.

The total long-term mortality and shed tag rate was 15% (307 mortalities and shed tags, 11 of which were "supertags"). Four tags were detected at the Locks but were not part of any formal release group. These may have been in fish that escaped incidentally through tank drains, although the outlets were screened. A remaining 23 tags were not accounted for after inventorying mortalities, shed tags, fish used in calibration testing, and tunnel reader detection data. These 23 tags may have been in fish that escaped through tank drains, or were shed and lost through the drain during tank cleanings.

The fish were divided among eight 0.9 m (3') diameter tanks set up inside in the bioassay lab of the building. Water used to hold all fish at the Metro Laboratory consisted of UV-treated lake water that was chilled when necessary to reach a target holding temperature of 10ºC (50ºF). Tanks were warmed to within a few degrees of ambient in the Ship Canal 24 hours prior to release to reduce the chance of increased stress or mortality due to temperature differences. The fish were designated for release as calibration test fish for evaluating the detection efficiency of the tunnel readers, and for use in the shoreline affinity tests. Gary Yoshida provided primary assistance and fish care at the Metro Laboratory.

2.3.3 Tributary Fish

Juvenile Chinook and coho salmon and steelhead trout of natural origin were caught and tagged at WDFW downstream migrant screw traps (see, e.g., Thedinga et al. 1996 for a description of a screw trap) in two streams in the Lake Washington system. The sites were located in (i) lower Bear Creek, below the railroad trestle, downstream of Redmond Way, and (ii) in the lower Cedar River just upstream from the Logan Street Bridge (Figure 1-1). Tagging was initiated at both sites on April 29, 2003. Tagging continued until July 2, 2003 in both streams. Tagging dates encompassed the peak of the outmigration period for naturally-produced smolts. A total of 2,765 fish were tagged and released in the Cedar River, and 4,349 fish in Bear Creek. Most of the fish were Chinook and coho salmon, although five steelhead trout and one sockeye salmon were tagged in the Cedar River. A primary goal of this portion of the study was to determine survival and migration characteristics of the main fraction of the Chinook and coho salmon smolt runs from each stream.

Fish were collected overnight in the screw traps. On each day of tagging, fish trapped the night before were transferred using sanctuary dip nets to 5 gallon buckets and then to a small tub containing MS-222. A PIT tag was inserted into the anaesthetized fish, which were then returned into a recovery bucket. Fish were allowed to recover fully from the anesthetic before they were released back directly into the river below the screw trap, usually within an hour after tagging. In general, all or nearly all Chinook, coho, and steelhead present in the trap that day were tagged, except for a few fish that were smaller than about 70 mm in length, which were too difficult to handle and for which the tag was large relative to the abdominal cavity size. Of fish held overnight to evaluate post tagging mortality and tag shed rates, no Chinook died or lost tags, and only one coho in Bear Creek died (see Lindsey Fleischer's report in Appendix A). Fish tagged in Bear Creek and the Cedar River were exclusively naturally reared. The tagged Chinook were likely all sub-yearlings, whereas it is likely that most of the coho and steelhead were yearlings.

2.3.4 Sammamish River, Lake Washington, and LWSC Fish

Chinook, coho, and sockeye salmon smolts were PIT tagged at a number of lake sites and in the Sammamish River between May 6 and June 12, 2003. The work was funded in part through a KCD grant to the City of Seattle and the WRIA 8 Technical Committee. Effort was not equal among all sites because of logistics, but the study plan called for sampling each site as many times as possible during the Chinook outmigration period until water temperatures exceeded approximately 17ºC. Some sites were sampled more frequently than others because of their strategic location and relative ease of catching fish. Fish were tagged and released on three occasions at the Marymoor Park site, on two occasions each at the Kenmore and Webster Point sites, and one occasion each at the Montlake Cut (fish were caught at Webster Point), Magnuson Park (ditto), and Madison Park sites. Fish were also tagged and released in the LWSC on the north shore at Gasworks Park (three times), east-southeast of Gasworks Park on the south shore of Lake Union (once), and on the north and south shores at the west end of the Fremont Cut (twice each). Additional sampling was either conducted or intended at some sites but no fish were tagged because of either low catch rates or excessive water temperatures. Details on the tagging operations and sites are provided in Appendix A. Fish were caught by seining, and tagging procedures were similar to those for the tributary fish.

165 Chinook salmon were also tagged and released on May 8, 2003 at Gene Coulon Park, in a collaborative effort between WDFW and the US Fish and Wildlife Service. Lindsey Fleischer, WDFW, was the tagger.

2.4 CALIBRATION TESTING OF THE TUNNEL READERS

The Chinook salmon held at the Metro Laboratory were designated primarily as calibration test fish. Calibration test fish were released in small groups on seven separate occasions between May 12 and June 19, 2003 to evaluate the detection efficiency of the tunnel readers. Groups of 50 fish were released directly into each flume using the same 10 cm I.D. PVC pipe used by Pfeifer and She (2002). Tests performed in 2002 suggested that there was no difference in detection efficiency when fish were introduced by hand into the mouth of the flume and through the pipe. There was no chance for escape during the tests as the fish were introduced into water moving faster than their swimming capability. Subsequent repeat detections of many calibration fish in 2002 and 2003 suggested that the sudden acceleration associated with the test did not harm the fish seriously (see results for details).

"Fish sticks" were used on up to four occasions to reduce the study's dependence on live fish being held at the Metro Laboratory. The sticks were constructed out of 30 cm lengths of 1.9 cm (sold as ¾") x 1.9 cm hemlock stock wood. A small hole was drilled and a PIT tag was inserted and sealed in. Two types of sticks were constructed: (1) where the tag was oriented parallel (0º) to the long axis of the stick, and (2) where the tag was oriented 45º to the long axis. Previous year's results indicated the fish sticks provided a reasonable index of detection efficiency, and that averaging the results of the 0º and 45º stick tests approximated the live fish results (DeVries 2003, 2002, 2001). Twenty sticks of each type were dropped sequentially into each flume, in such a manner that they entered the tunnel reader approximately parallel to the flow streamlines thereby mimicking the passage of PIT tagged fish. The sticks were painted with bright fluorescent colors to facilitate retrieval using a boat below the flumes. The associated error in determining detection efficiency of a given tag orientation was therefore 5%, with an overall detection efficiency error of 2.5%.

The number of test fish and fish sticks that were detected was determined from the file created by MINIMON. Detection efficiency was calculated as the ratio of number detected to number released in each flume, expressed as a percentage. Electronic marker notes were placed in the computer file immediately before each live fish group was released and the time noted in field books so that the detected tag codes and discrete flume tests could be distinguished accordingly. A Fortran program was written to extract the fish stick data and summarize those results.

The first fish test, conducted on May 12, 2003, involved releasing up to 100 fish in each flume with "supertags" and a similar number of fish with standard tags. The number of fish released reflected the number of fish available with supertags after holding and transport mortalities. A total of 568 fish were released. The goal was to compare detection efficiencies of the two tag types in each flume. Fish were not released in Flume 4A because its detection rate has been consistently near 100% in previous years and to maximize the number released in the other flumes, which have typically had a lower detection efficiency.

2.5 EVALUATION OF SHORELINE AFFINITY AND PROPORTION USING SMOLT FLUMES

As indicated above, juvenile Chinook salmon were captured near Gasworks Park and released near the south and north shores at two different locations within the LWSC to evaluate shoreline affinity and the proportion using the smolt flumes. The ad hoc experiment continued the one initiated in 2002 and was designed to evaluate simultaneously, to first order, both the issue of shoreline affinity and proportion using the flumes (P_{SF}), while accepting a low level of statistical precision because of a limited number of tagged fish available for the test. In addition to indicating the approximate order of magnitude of the degree to which shoreline affinity is important and the approximate value of P_{SF}, the results were expected to indicate which issue should be addressed in greater depth in the future using greater sample sizes and a more rigorous sampling design. The design called for releasing replicate groups of fish near the north and south shore the same day at a number of locations in the LWSC. Release locations are indicated in Figure 2-4.

The experiment was based on the assumption that survival to the Locks is high (>95%), particularly from the Metro Laboratory location at the eastern end of the Fremont Cut, which seemed reasonable based on previous years' results. By ignoring the confounding effect of survival, only the proportion using the flumes and the degree to which mixing occurs as fish approach the Locks can be treated as unknowns. These two unknown quantities can be evaluated to first order by releasing groups of fish on the north and south side of the LWSC at different distances from the Locks, and evaluating whether north-south mixing occurs. Letting N_{FSi} and N_{FNi} be the numbers from each release group $\boldsymbol{i}$ detected in the flumes, corrected for detection efficiency, the null hypothesis that can be tested is that the average of the ratio (N_{FSi}:N_{FNi}) equals 1 (i.e., no shoreline affinity). The alternate hypothesis is that the average ratio is greater than 1.

The proportion using the flumes was evaluated by plotting the ratio against distance to the flumes, on the basis that a relatively consistent proportion using the flumes for a given side of the ship canal would be indicated by an asymptotic relationship in the plot. If there is shoreline affinity, then the asymptotic value would differ between the north and south release groups; if

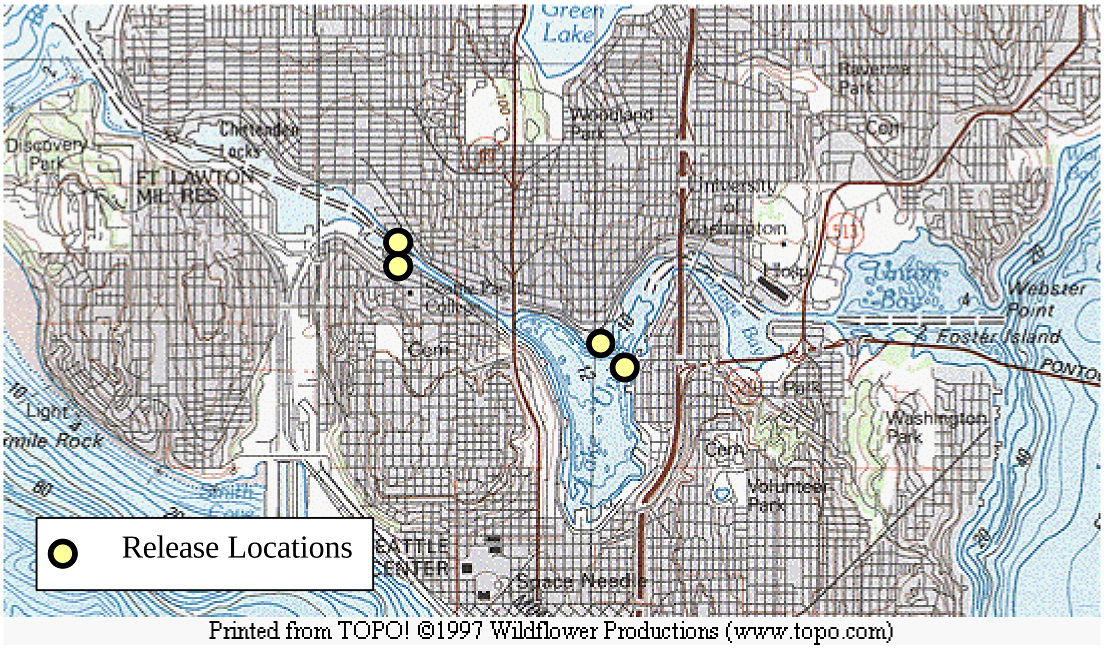

Figure 2-4. Locations where PIT tagged juvenile hatchery Chinook salmon were released in 2003 to evaluate shoreline affinity within the LWSC and the proportion using the smolt flumes at the Locks.

not, the two curves should converge. The selected release locations also facilitate a crude evaluation of where mixing was more likely to occur in the LWSC.

Numbers of samples and release locations were constrained by logistics, where greater emphasis of the KCD-funded effort was placed on Lake Washington and Sammamish River sites. The primary goal was to supplement the more extensive data collected in 2002.

2.6 DETECTION STRATEGY

The 2003 study relied primarily on releasing fish at multiple locations in the watershed and detecting them at the Locks, although some opportunistic recaptures were made during tagging operations at different locations along the passage route. As in previous years, not all of the passage routes through the Locks were monitored. There were no detection facilities or sampling conducted in the small lock, the other spillway gates, the saltwater drain, or the fish ladder. An unknown proportion of tagged fish therefore passed downstream without being detected. This feature of the study influenced the accuracy and precision of survival estimates, but did not substantially influence evaluations of overall migration and passage characteristics.

2.7 DATA ANALYSES

2.7.1 Physical Characteristics of the Fish

Other than general body condition at time of tagging, the only physical characteristic of the tagged fish that was measured was total length at time of tagging, and whether the fish could be discerned to have been of hatchery origin. Almost all of the tagged fish were measured, with the exception of a small number whose lengths were inadvertently not recorded by the digitizing system. Information was not available regarding growth and length at time of passage at the Locks. Recaptures during tagging operations were evaluated opportunistically for growth characteristics, however. Fish lengths at time of tagging were used primarily to compare potential size differences between the detected and undetected fish by means of frequency analysis using a Chi Square test of observed (=detected fish) and expected (=released fish) frequencies (Zar 1984). This was done for each group as a whole, irrespective of release date to see if there were any population-level differences in fish length arriving at the Locks compared with lengths at other points along the migration route.

The length data from the Cedar River and Bear Creek tagging operations were also used to compute average lengths of tagged fish at different times at each location. The results were plotted against tagging date to identify temporal trends, if any, that might potentially influence size-dependent survival to the Locks, or suggest partitioning of the length frequency data by tagging date.

2.7.2 Migration Behavior

The dates of PIT tag detections at the Locks were used to identify patterns and differences in migration timing, total travel time until passage through the flumes, and average migration rate among the different test groups. Average migration rate was computed by dividing travel distance by the number of days between release and detection at the Locks. Travel distances were determined using the “Topo” software package (™Wildflower productions) by tracing assumed migration routes five times on electronic topographic quad sheets and averaging the numbers calculated by the program. Routes in the LWSC were assumed to follow the mid-channel line on average, with the exception of the shoreline affinity test fish released near Gasworks Park, which were assumed to follow the south shore of Lake Union (Figure 2-4). Routes through Lake Washington were assumed to follow the west shoreline from either the mouth of the Cedar River, or the mouth of the Sammamish River, where the path as traced ran within approximately 400 m (¼ mile) offshore (note, however, that some fish exiting the Sammamish and Cedar rivers were determined during this study to have likely migrated along the eastern shore of Lake Washington; see Section 4.0). Traced routes through Lake Sammamish followed both west and east shorelines and an average was taken of the two.

2.7.3 Passage Behavior at the Locks

The dates and times of PIT tag detections at the Locks were used to identify patterns and differences in seasonal and daily passage timing among the different test groups at the Locks. Tag codes were also evaluated for recycling times through the Locks, based on repeated detections at the tunnel readers and/or in purse seine samples in the large lock.

To evaluate the influence of filling of the large and small locks on smolt passage through the flumes, detection times were compared with times at which various components of the Locks were operating. Fortran programs were written that counted the number of detections that occurred while (i) the small and large locks were filling and for five minutes thereafter ("fill" period), and (ii) until the time of the next fill sequence ("between-fill" period). Time of lock openings were determined from records maintained by the Lockmaster, and the time for each lock to fill was determined as a function of tide elevation and observations of fill times at different tide levels. In the case of the large lock, the fill time was also a function of whether one or both chambers were being filled (although in 2003, both chambers were consistently filled as the middle gate was not closed during the study) and how fast the water was allowed to flow through the culverts (i.e., continuous, gradual, or intermediate fill patterns). A post-fill period of five minutes was selected arbitrarily (absent specific data), assuming that fish continued to swim about actively for a short period after the velocity field in the spillway dam forebay returned to approximately steady-state, non-fill conditions. The exact time for velocities to return to steady state has not been determined in recent measurements of velocity fields above the Locks, but appears to be less than 5 minutes based on available measurements (Johnson et al. 2001). Velocity transients associated with density currents when the upper gates are opened (Lingel 1997) were not considered.

The two sets of numbers generated by the programs were compared using t-tests to evaluate the hypothesis that transient changes in water currents in the vicinity of the Locks caused by lock filling operations were associated with increased passage through the flumes. The null hypothesis was that passage was not significantly different in pairwise comparisons of sequential observations of numbers of fish passing through the flumes during and between fills.

2.7.4 Survival Estimation

Survival could not be estimated to high accuracy or precision because (i) the proportion of tagged fish using the smolt flumes (P_{SF} ; compared with other routes through the Locks) could not be estimated to high accuracy or precision, (ii) of variable tunnel reader detection efficiencies (Section 3.2), and (iii) seasonal variation in detection rates, possibly related to increasing water temperature in the LWSC, was likely reflected in a change in the proportion using the flumes (Section 3.6). In addition, fish released in all LWSC and Lake Washington sites except at Kenmore may have experienced non-quantified post-tagging mortality because of relatively warm surface water temperatures in 2003 (see Appendix A).

Migration route segment survivals were evaluated for different Chinook and coho salmon release groups by comparing the ratios for two sites of the number of fish detected at the smolt flumes ($N_{group\ SF}$) to the number of fish released ($N_{group\ REL}$). The total number of PIT tagged fish from each release group passing through the four smolt flumes was estimated using an average detection efficiency for each flume i ($Ç_{SFi}$; determined during the calibration testing):

$$\hat{N}_{group_{SF}} = \sum_{i=1}^{4} \hat{N}_{group_{SF\ i}} = \sum_{i=1}^{4} \frac{N_{group_{SF\ i}}}{\overline{E}_{SF\ i}}$$

Because the proportion using the flumes P_{SF} was not known with confidence, overall survival of each group (S_{group}) could not be estimated more traditionally as:

$$\hat{S}_{group} = \frac{\hat{N}_{group_{SF}}}{\hat{P}_{SF}\ N_{group_{REL}}}$$

Absent good estimates of P_{SF}, survival can be estimated instead for a route segment between two release locations when the assumption that the detection probability (i.e., P_{SF}) of each group is the same at the Locks can be approximately met. This assumption is reasonable when the two groups pass through the flumes on roughly the same date. In addition, it was assumed that survivals of fish migrating through adjacent segments were independent. Migration route segment survival between two points 1 (upstream) and 2 (downstream) were correspondingly estimated on a weekly basis using:

$$\hat{S}_{1-2} = \frac{\hat{S}_{group1}}{\hat{S}_{group2}} = \frac{\hat{N}_{group1_{SF}} / \hat{N}_{group1_{Rel}}}{\hat{N}_{group2_{SF}} / \hat{N}_{group2_{Rel}}}$$

The appropriate release group(s) to include in the calculation was identified by comparing median travel times from the different release locations, and going back in time accordingly. The variance of this estimate is a function of the variances of the ratios in the numerator (p_1) and denominator (p_2), per the Taylor Series approximation:

$$\hat{V}ar\left(\hat{S} = \frac{p_1}{p_2}\right) \approx \frac{\hat{V}ar(p_1)}{(p_2)^2} + \frac{(p_1)^2\,\hat{V}ar(p_2)}{(p_2)^4}$$

The variance of each ratio p_1 and p_2 can be approximated assuming a binomial distribution (Zar 1984). An example of approximate 95% confidence limits for a segment survival estimate of 0.75 and various release group sizes is given in Figure 2-5.

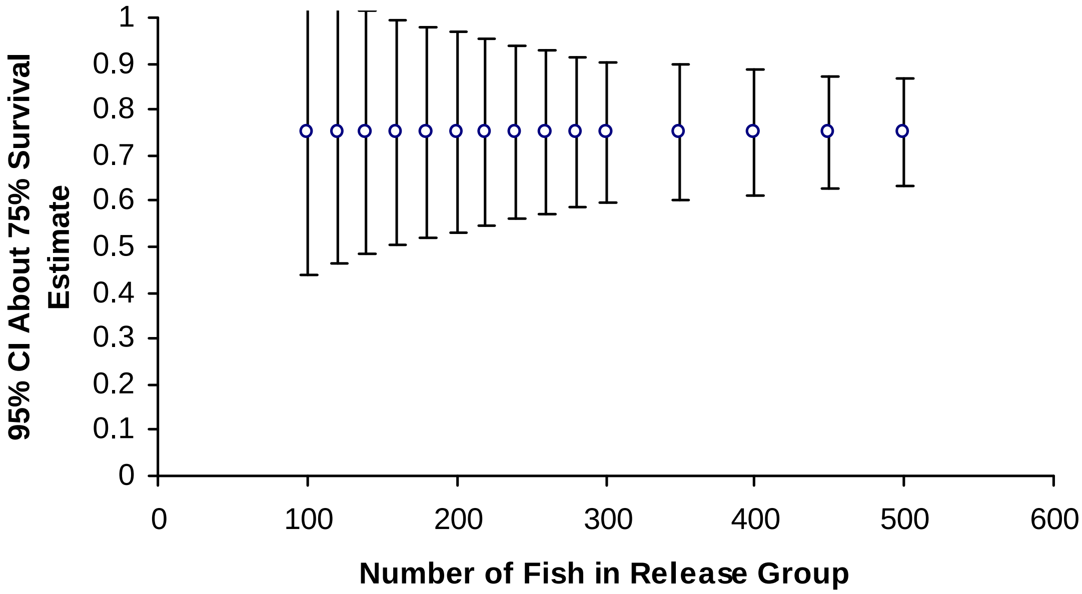

Figure 2-5. Approximate 95% confidence limits for an example migration route segment survival estimate of 0.75 and different PIT tag release group sizes, 2003 Lake Washington GI study.

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3. RESULTS

The results of this study were strongly influenced by low flows into Lake Washington in 2003, more so than in 2000 and 2001 because of an extremely dry spring. Many streams and rivers in western Washington experienced record low flows in 2003 (e.g., Issaquah Creek; provisional USGS data). There was insufficient water available to run all four flumes at the same time. Figure 3-1 shows the times that the flumes were open during the study according to logs kept in the lock control tower and PIT tag detection times. At most three flumes were open continuously until May 8, 2003. There was no spill of water through Spillway 1 during the study period. Beginning June 3, 2003, the USACE began to shut down flumes at night to conserve water, given that previous years' studies had indicated that more than about 95% of passage occurred during daylight hours. Flume passage was provided through July 10, 2003, at which time the decision was made to shut down the flumes for the season in response to a tailing-off of PIT tag detections to zero several days in a row, reflecting surface water temperatures exceeding thermal tolerance limits. Flume 4B was selected as the final flume to keep open because calibration testing indicated Flume 5B detection efficiencies were lower and more likely to decrease than 4B, and because previous results have indicated that the larger flumes generally pass more fish in sum. There were also short periods when the flumes were closed for maintenance. Consequently, the flume coverage for PIT tags was neither continuous nor consistent.

In contrast with previous years, there were no serious computer problems in 2003 resulting in lost data on any one of the two computers (main and backup). BAE staff checked the computers daily on weekdays to ensure they were running properly.

The flumes operated long enough that the sockeye and coho salmon outmigrations were essentially complete and the numbers of tagged Chinook salmon passing through the flumes had decreased substantially to near zero, consistent with visual flume count data (P. Johnson and K. Bouchard, personal communication). Behavioral patterns evident in the data were therefore unlikely to have been influenced significantly by systematic error. These patterns relate to migration, passage, and the transition to saltwater, and provide significant insight into the basic biology of juvenile outmigrant salmonids in the Lake Washington system, as described in the remainder of this section.

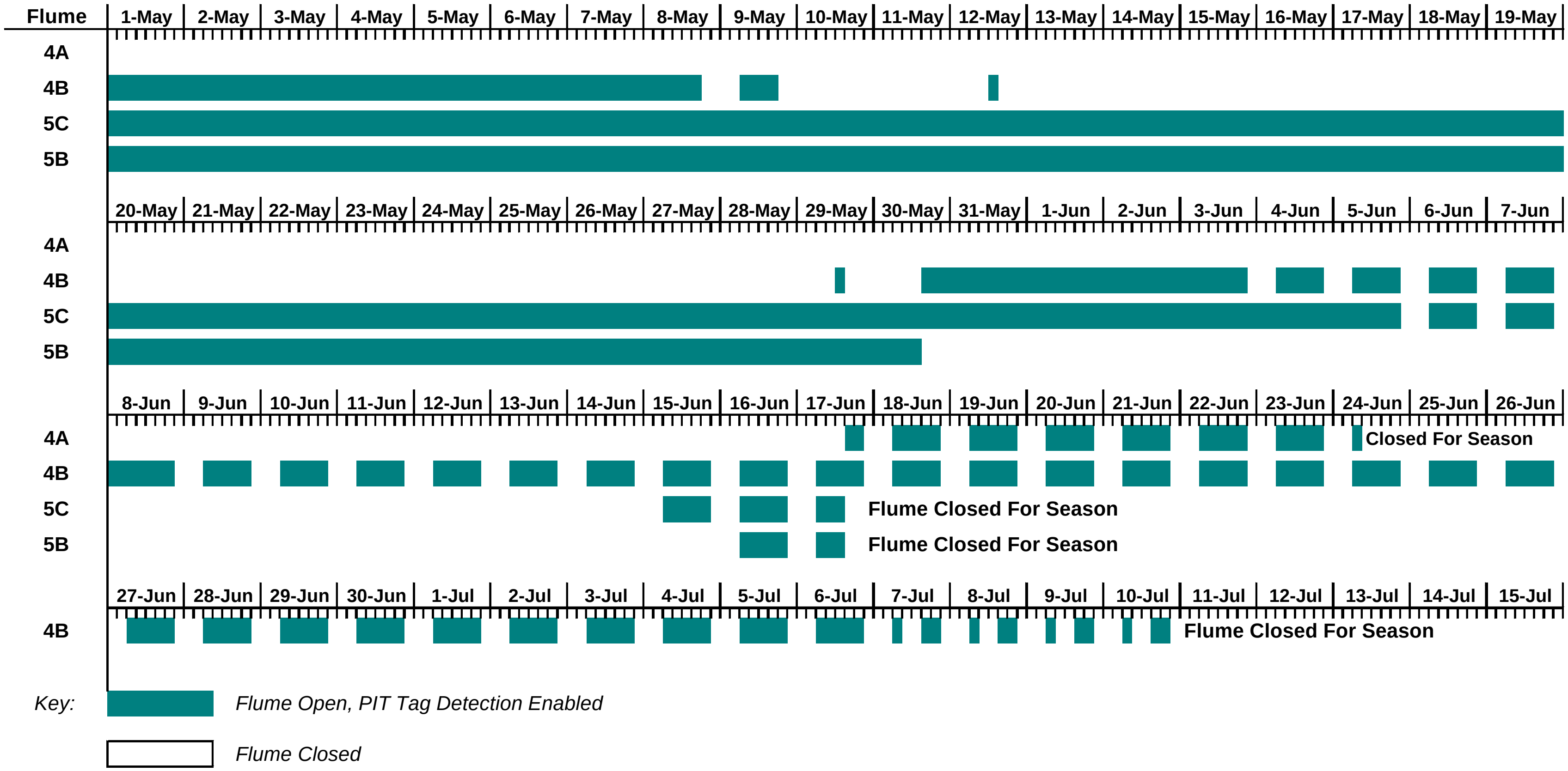


Figure 3-1. Times that the smolt flumes were open at the Locks during the 2003 PIT tag study after the first test fish were released.

This section focuses predominantly on results for 2003, and in a few cases presents previous years' results for comparative purposes. Section 4 includes a more thorough, synoptic comparison of selected data across all four years of study.

3.1 PIT TAG DATA SUMMARIES

Table 3-1 summarizes numbers of fish and the locations at which they were tagged and released. The estimated numbers passing through the flumes reflect corrections based on average detection efficiencies determined for each flume in the calibration tests. Figures 3-2 and 3-3 depict the numbers and dates of tagging for each Chinook and coho group and release location. The numbers and dates of release of each species at each location, and the corresponding numbers detected in each flume are also presented in tabular form in Appendix B.

There were thirteen tags detected in the tunnel readers that were not identified in the 2000, 2001, 2002, or 2003 tagging files, probably because they were not detected by the tagging station equipment, so the origin release date, and/or species of those fish could not be determined conclusively. Of these, two tags did not appear to come from the Lake Washington GI studies based on their tag numbers, but they were not listed in the PTAGIS database. Another two of these tags were likely fish tagged in 2002 or 2001 based on the tag number. Two more tags were detected that were not in the tagging files, but their origin was deduced because the identification number of the bags they came in was noted during tagging; those tags were edited into the tagging files accordingly. Two tags were also detected from a separate pilot study involving acoustic tags.

3.2 CALIBRATION TESTING AND FLUME/TUNNEL READER OPERATION PROBLEMS

Detection efficiency was generally similar to levels experienced in 2001 and 2002, although the frequency of testing both fish and fish sticks on the same date was reduced in 2003. The magnitude of and variation in detection efficiency decreased and increased, respectively, with flume size (Figure 3-4). Guidelines for the Columbia River require a minimum detection efficiency of 95% with four coils operating, and most systems there operate in the 98-100 percent efficiency range (D. Park, Biomark, personal communication). Beginning in late April after study fish were released, detection efficiencies based on calibration test fish averaged 100% and 97% in Flumes 4A and 5C, respectively, and 84% in Flume 4B. These numbers were comparable to previous years. As in 2002, detection efficiency was more variable in Flume 5B which again exhibited a downward drifting trend in efficiency, although the average efficiency was similar to that of Flume 4B (84%).

Table 3-1. Summary of 2003 PIT tag release and recapture numbers, Lake Washington GI Study

Species	Origin	Issaquah Creek Hatchery	Marymoor Park	Bear Creek	Kenmore	Magnuson Park	Webster Point	Cedar River	Gene Coulon Park	Madison Park	Montlake	Lake Union	Metro Laboratory
Total Numbers Tagged and Released:													
Chinook	Natural	--	10	2305	7	--	35	1726	165	5	4	72	21
	Hatchery	992	1154	--	753	--	259	6	--	291	199	646	378
Coho	Natural	--	--	2044	--	--	--	1027	--	--	--	--	--
	Unknown	--	--	--	50	--	--	--	--	--	--	--	--
Sockeye	Natural	--	--	--	--	--	--	1	--	--	--	--	--
	Unknown	--	--	--	--	335	--	--	--	--	--	--	--
Steelhead	Natural	--	--	--	--	--	--	5	--	--	--	--	--
Total Numbers Detected in Smolt Flumes:													
Chinook	Natural	--	1	682	5	--	0	449	13	0	1	12	2
	Hatchery	236	318	--	302	--	6	1	--	22	24	84	69
Coho	Natural	--	--	1234	--	--	--	555	--	--	--	--	--
	Unknown	--	--	--	13	--	--	--	--	--	--	--	--
Sockeye	Natural	--	--	--	--	--	--	0	--	--	--	--	--
	Unknown	--	--	--	--	16	--	--	--	--	--	--	--
Steelhead	Natural	--	--	--	--	--	--	1	--	--	--	--	--
Estimated Total Numbers Passing Through Smolt Flumes:													
Chinook	Natural	--	1	817	5	--	0	523	15	0	1	14	2
	Hatchery	276	384	--	365	--	6	1	--	24	26	109	74
Coho	Natural	--	--	1472	--	--	--	682	--	--	--	--	--
	Unknown	--	--	--	16	--	--	--	--	--	--	--	--
Sockeye	Natural	--	--	--	--	--	--	0	--	--	--	--	--
	Unknown	--	--	--	--	19	--	--	--	--	--	--	--
Steelhead	Natural	--	--	--	--	--	--	1	--	--	--	--	--

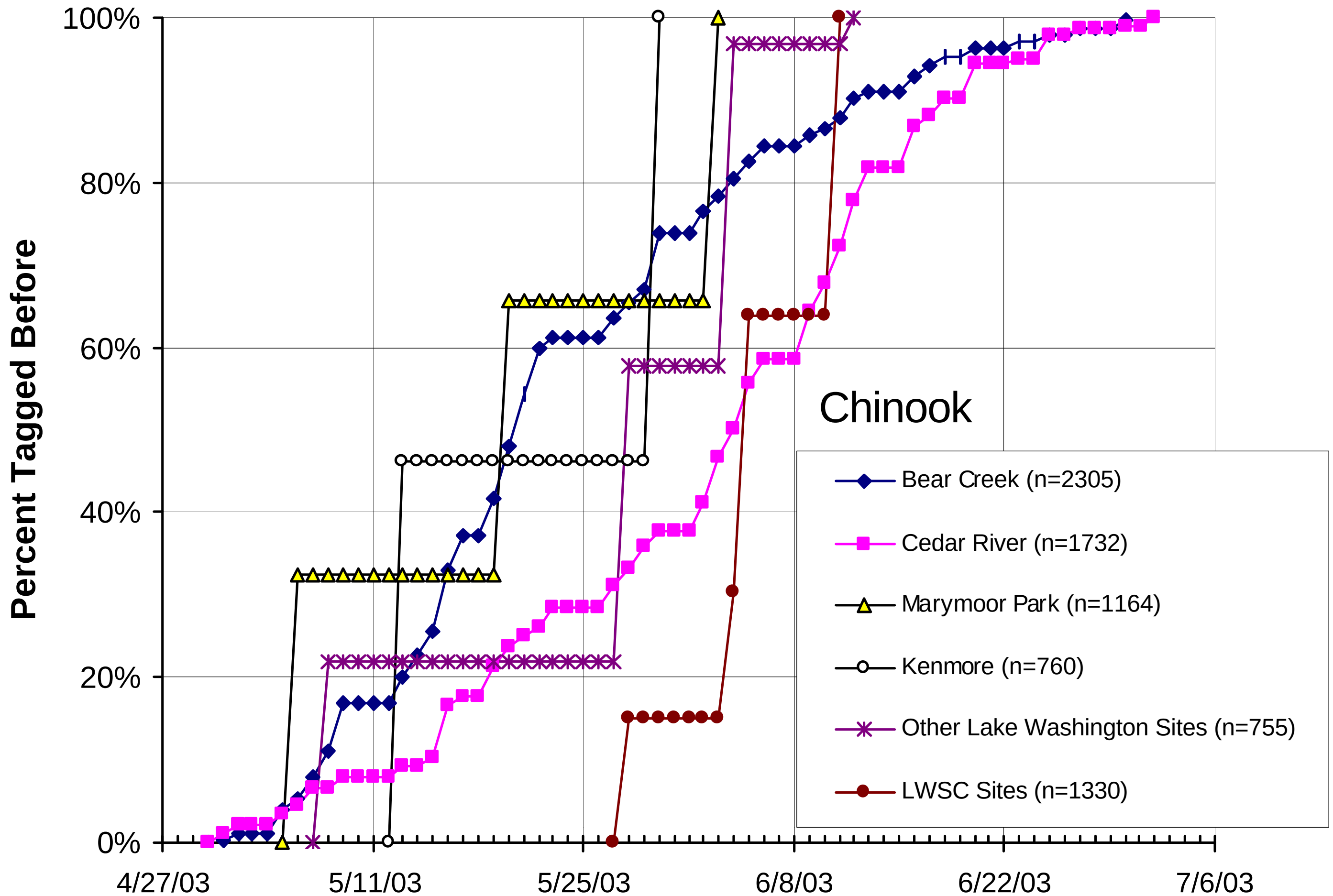


Figure 3-2. Cumulative frequency distributions of juvenile Chinook salmon PIT tagging numbers by date and location, 2003 Lake Washington PIT Tagging study.

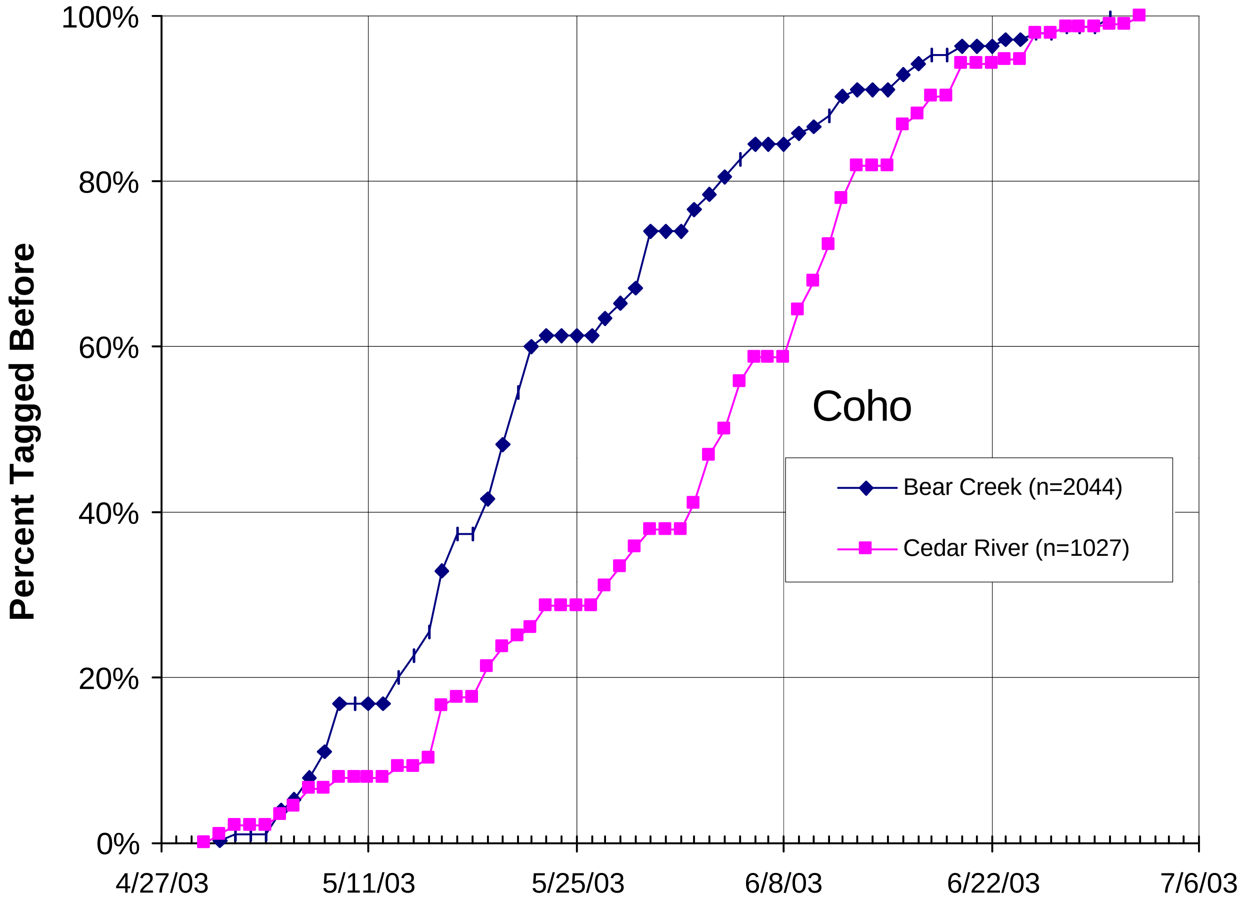


Figure 3-3. Cumulative frequency distributions of juvenile coho salmon PIT tagging numbers by date and location, 2003 Lake Washington PIT tagging study.

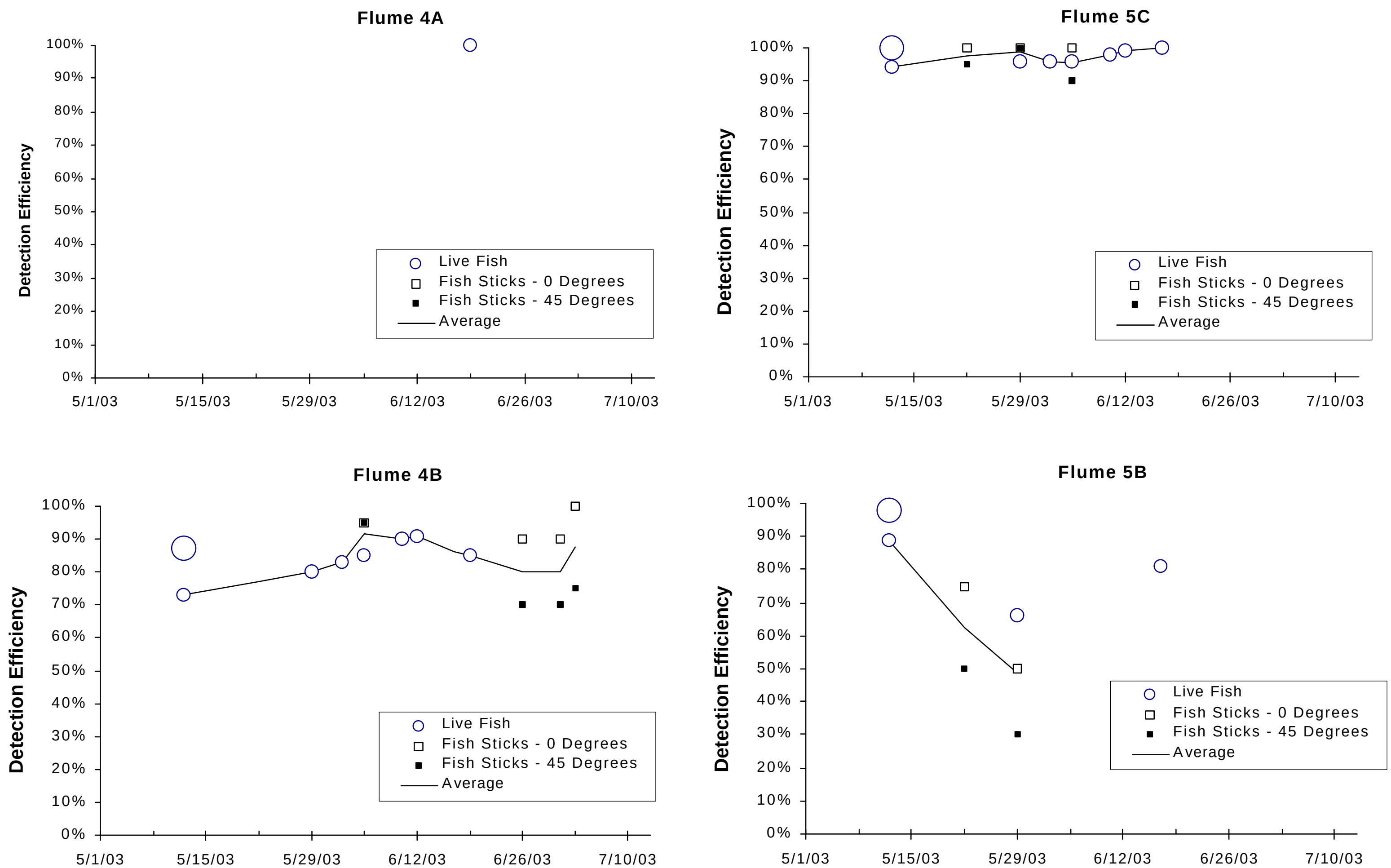


Figure 3-4. Results of calibration tests of tunnel detector efficiency at the Locks using PIT tagged fish and fish sticks released directly into each flume, 2003 PIT tag study. The larger open circles represent the results for “supertags.”

The calibration tests also indicated that the fish sticks with tags oriented parallel to the flow in the flumes were detected with slightly greater efficiency on average than were live tagged fish (Figure 3-5). In contrast, the fish sticks with tags oriented at 45^o were detected at a similar or slightly lower rate as the tagged fish. Visual observation of fish passing through the flumes indicated that they swim vigorously facing upstream, and thus their bodies are not always oriented optimally for detection. With the exception of the one test in Flume 5B, the average of the 0^o and 45^o results was generally similar to that using live fish (Figure 3-5). Consequently, the results for test fish (when used), 0^o sticks, and 45^o sticks were averaged on each test date, and daily detection efficiencies were interpolated for each flume using the computed averages. Dates when the coils were adjusted were used as a breakpoint in the interpolation to reflect the trends before and after. The daily detection efficiency estimates were used to adjust the total numbers of PIT-tagged fish passing through the flumes, as described in Section 2.7.4.

The test on May 12, 2003 indicated that the “supertags” had a consistently higher detection efficiency than the standard tags in the medium and larger size flumes (Figure 3-4).

3.3 FISH LENGTH CHARACTERISTICS

Fish lengths were determined primarily at the time of tagging and should not be used to infer size at time of passage at the Locks. Figures 3-6 through 3-12 depict the range and frequency distributions of lengths of the fish that were tagged in each group, and compares the distributions with those of the fish that were detected at the Locks. The figures also depict the change in mean length of fish at the LWSC and tributary locations where tagging continued over the course of the passage season. In general, there was limited evidence of a consistent effect of fish size overall on detection rate at the Locks, indicating that tagged fish generally had an equal probability of passing through the flumes. In all cases, the two distributions were not significantly different and overlapped at the 5% significance level (Chi-Square test of expected frequencies; Locks = observed, tagging = expected).

Mean lengths of juvenile Chinook captured in Bear Creek and the Cedar River appeared to exhibit different patterns, consistent with previous years. Mean lengths increased in Bear Creek until around May 28, 2003, when apogee occurred (Figure 3-7; a similar trend was observed in the 2002 data on June 4, 2002). Lengths then remained similar until around June 25, 2003, after which they appeared to increase again.

Partitioning the Bear Creek length data into two groups divided by May 28, 2002 indicated different temporal patterns existed. Overall, Bear Creek Chinook detected at the Locks were not significantly different in size from all fish released (Figure 3-7). The same was true for fish

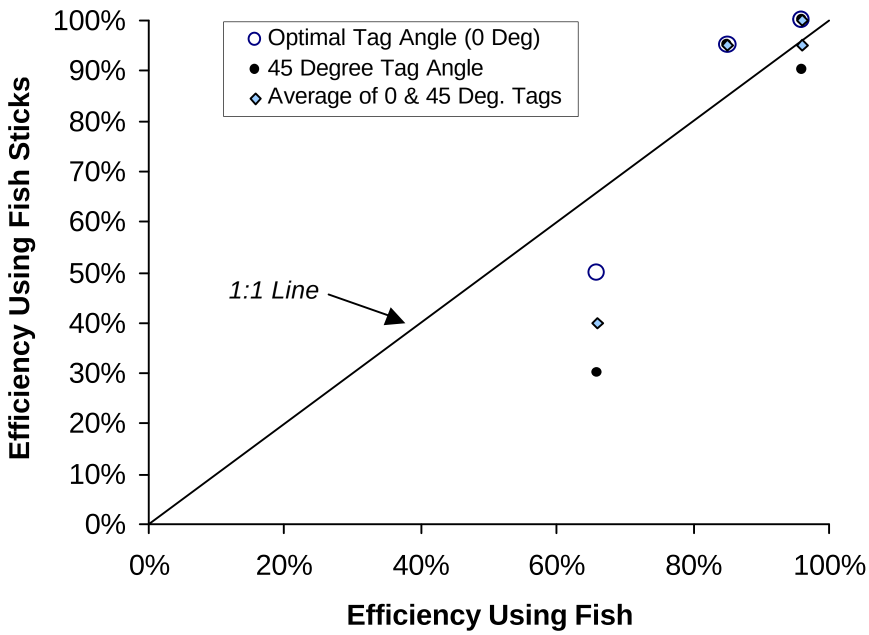


Figure 3-5. Comparisons of tunnel detector efficiencies at the Locks determined using live fish and fish sticks, 2003 Lake Washington PIT tag study.

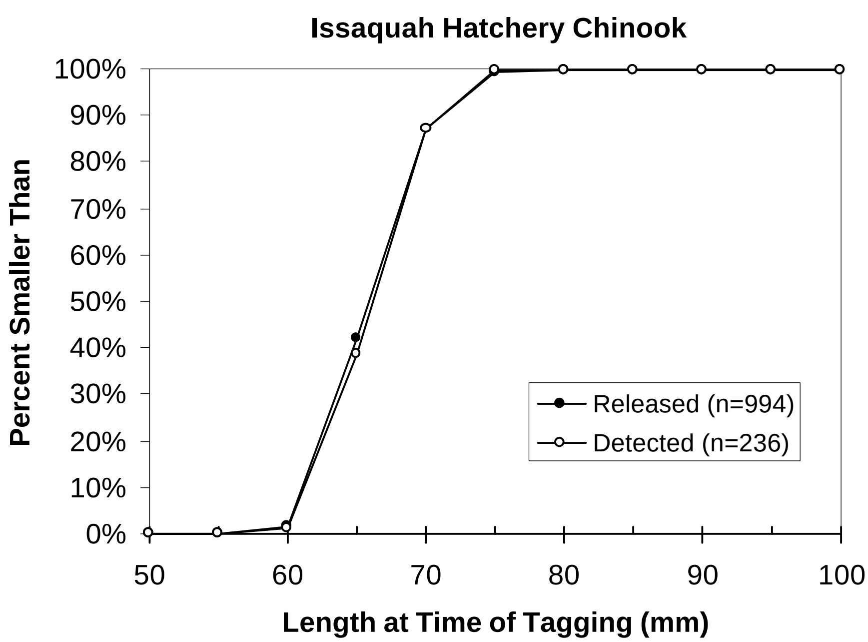
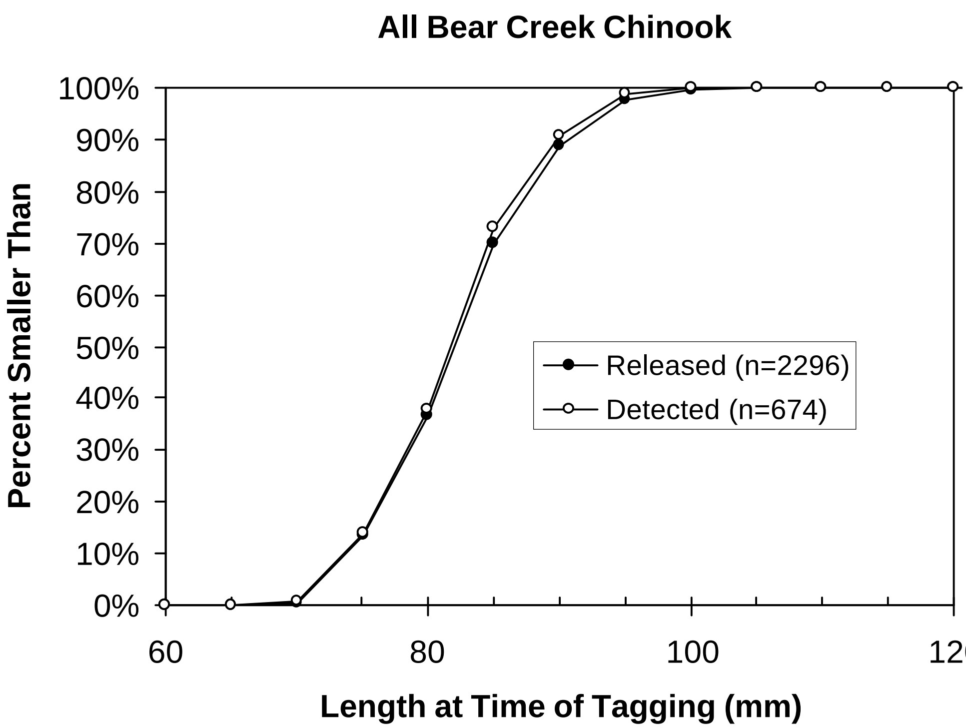


Figure 3-6. Cumulative frequency distributions of lengths of tagged and detected Chinook salmon released at the Issaquah Hatchery, 2003 PIT tagging study.



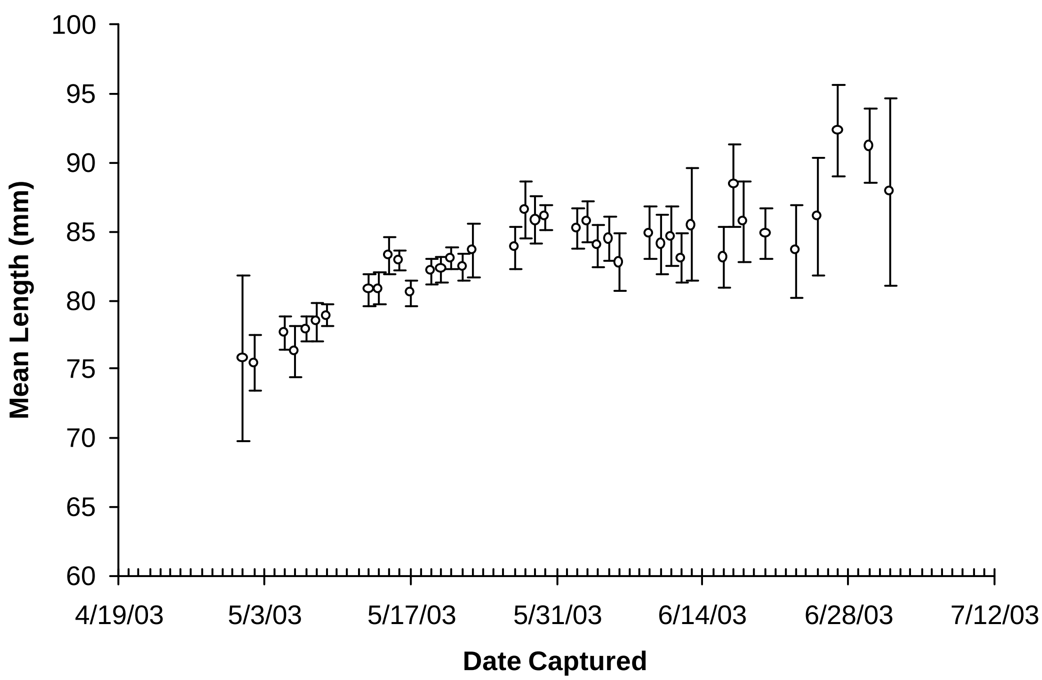
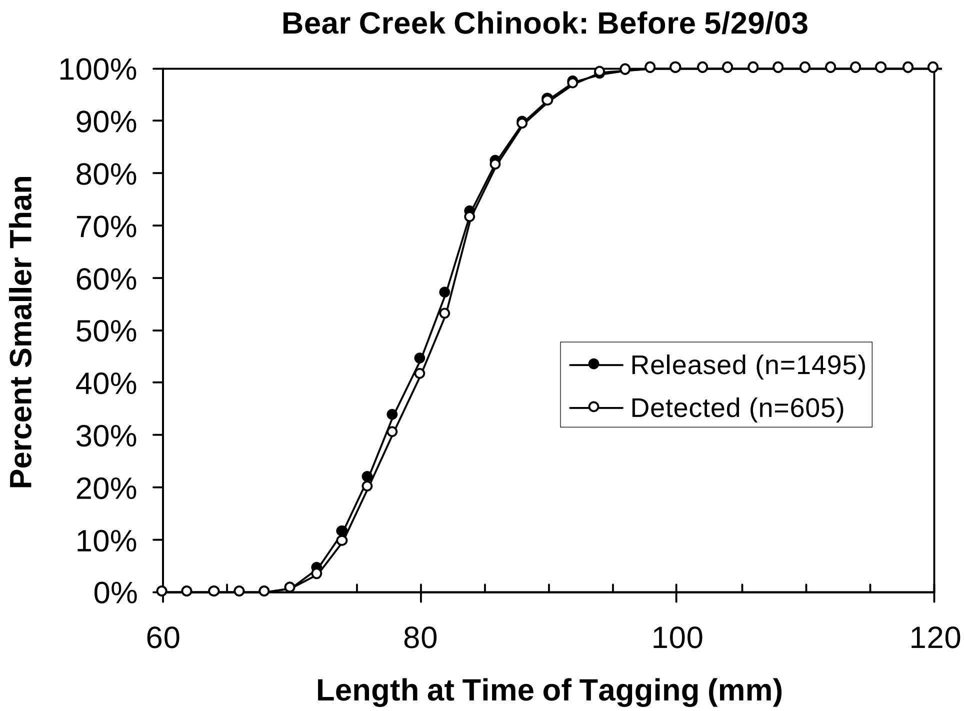


Figure 3-7. Cumulative frequency distributions of lengths of tagged and detected Chinook salmon caught in Bear Creek (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2003 Lake Washington PIT tag study.



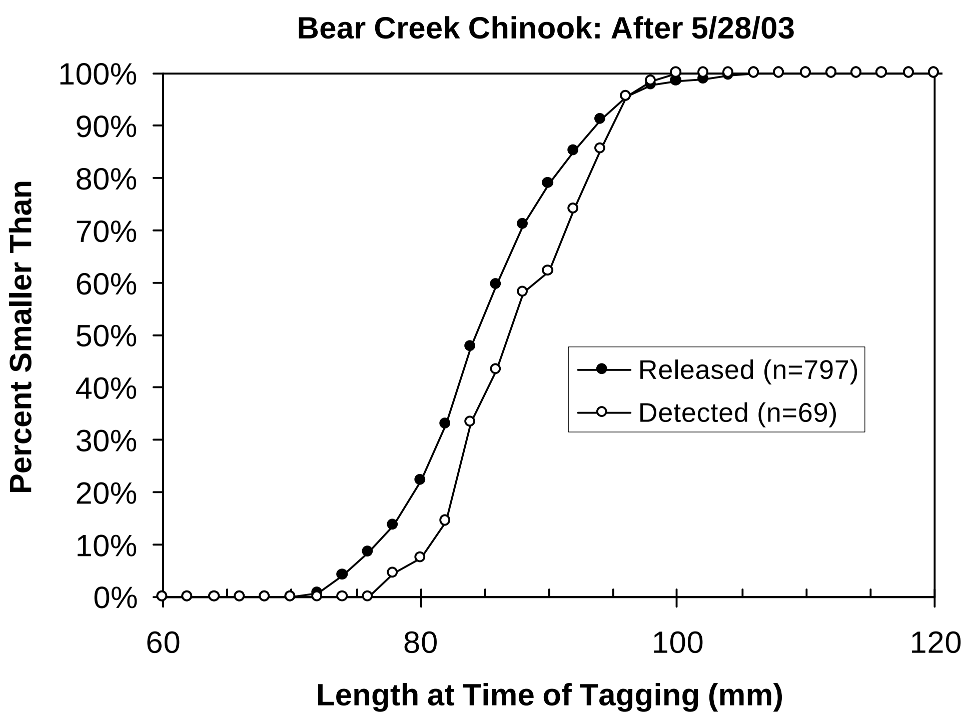
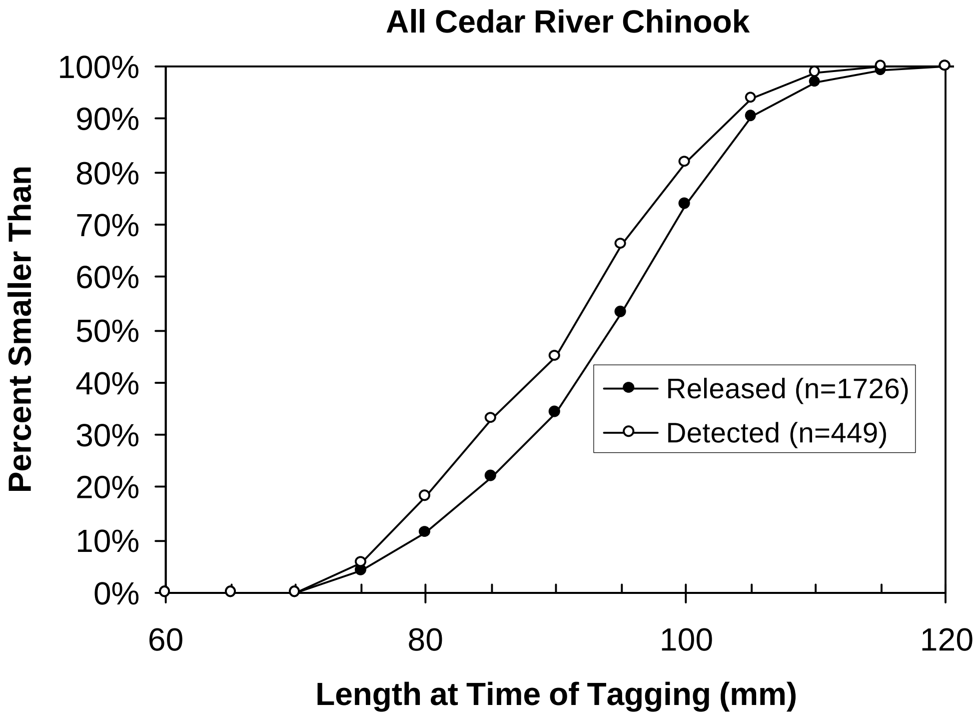


Figure 3-8. Cumulative frequency distributions of lengths of tagged and detected Chinook salmon caught in Bear Creek before 5/29/03 (top) and after 5/28/03 (bottom), 2003 Lake Washington PIT tag study.



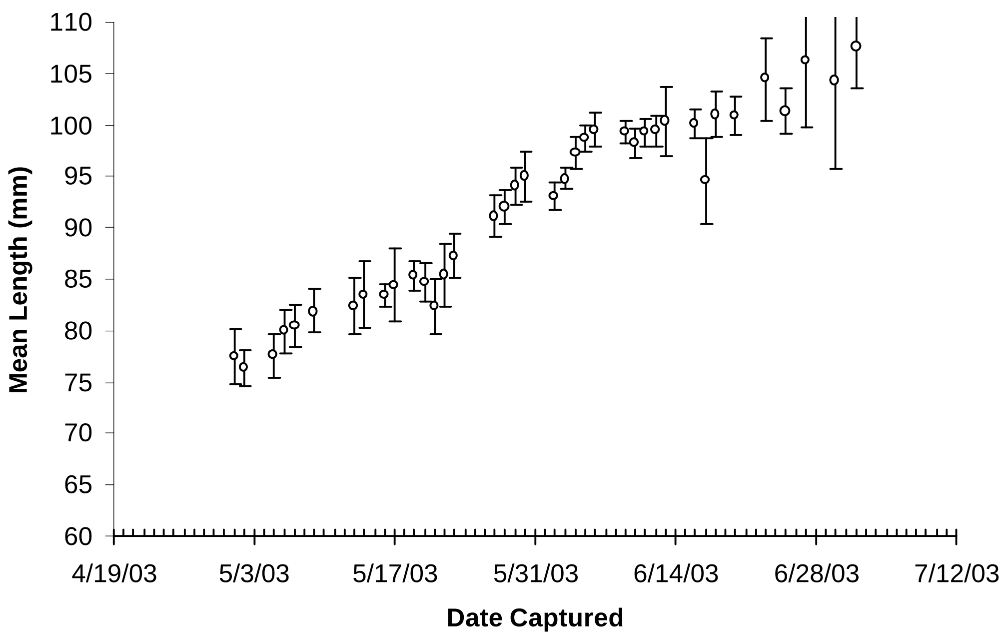
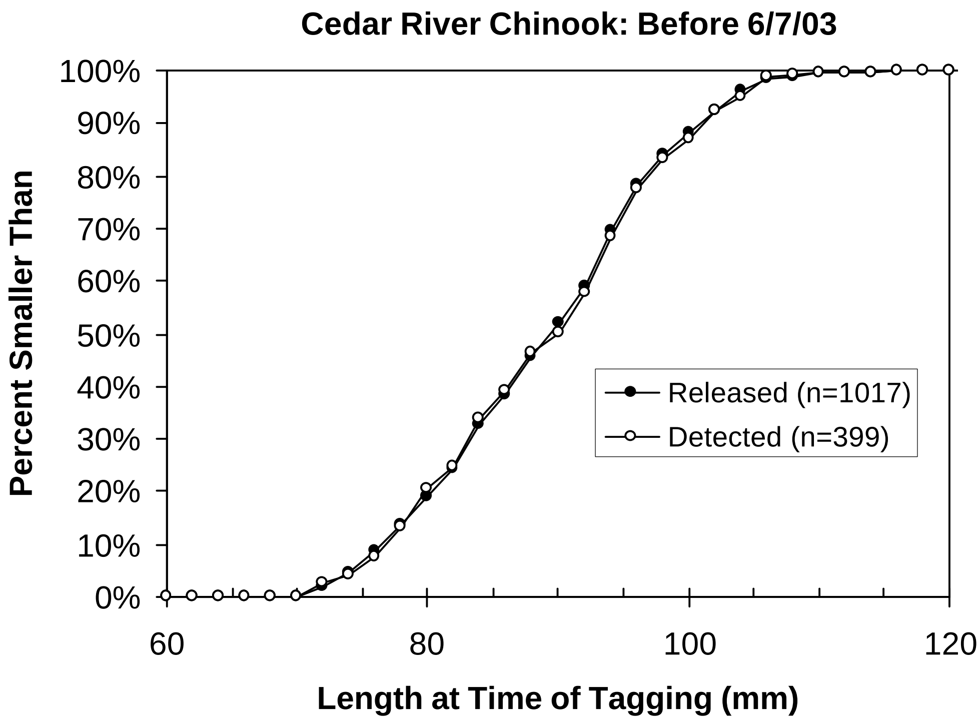


Figure 3-9. Cumulative frequency distributions of lengths of tagged and detected Chinook salmon caught in the Cedar River (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2003 Lake Washington PIT tag study.



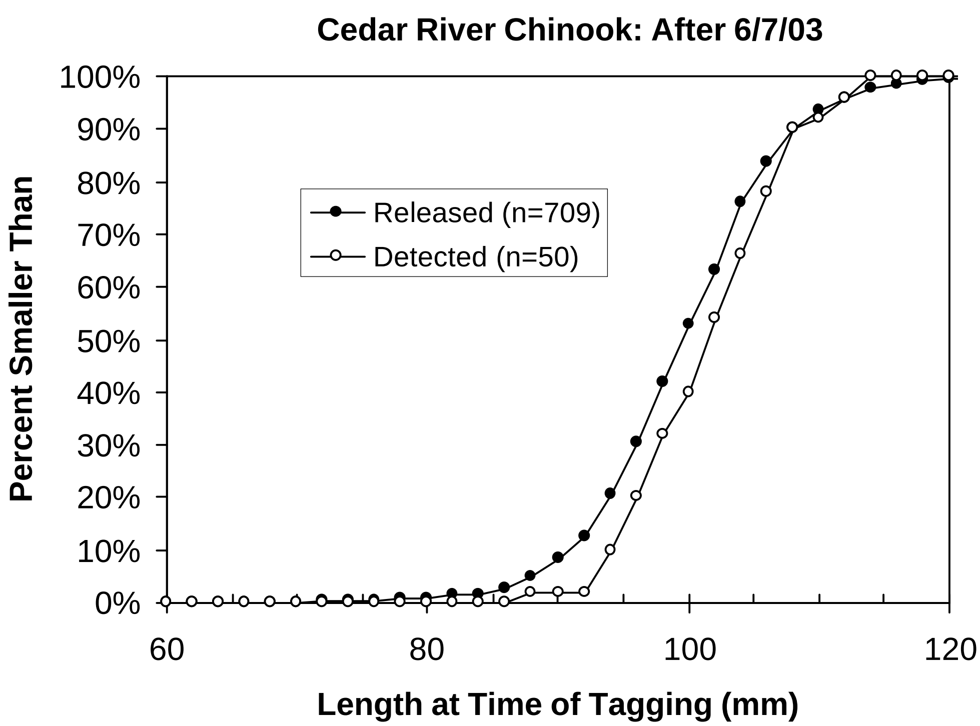
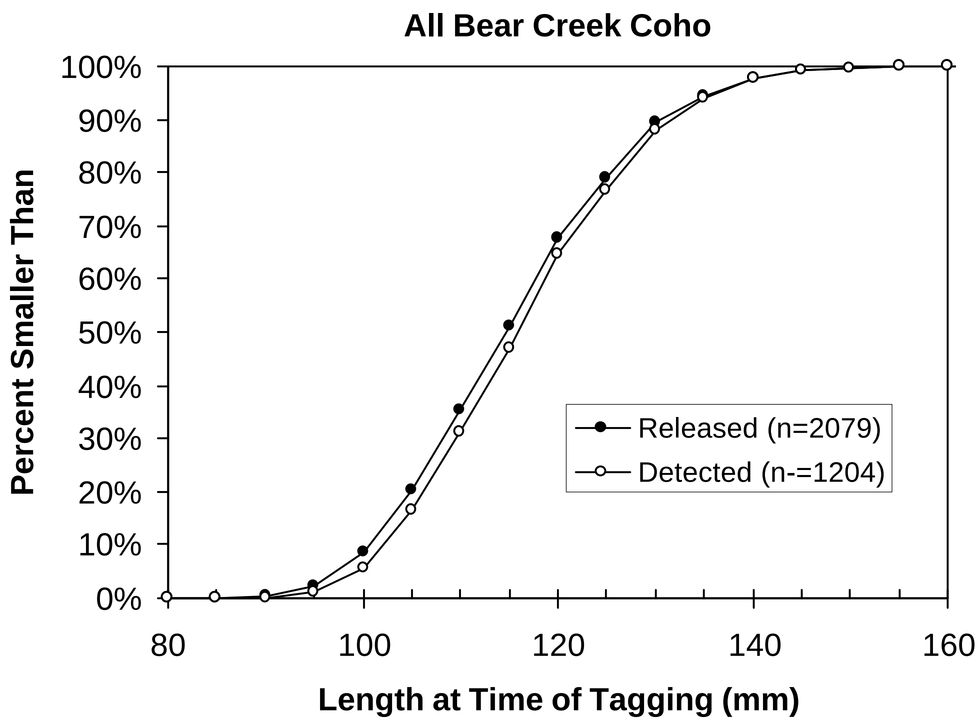


Figure 3-10. Cumulative frequency distributions of lengths of tagged and detected Chinook salmon caught in the Cedar River before 6/7/03 (top) and after 6/7/03 (bottom), 2003 Lake Washington PIT tag study.



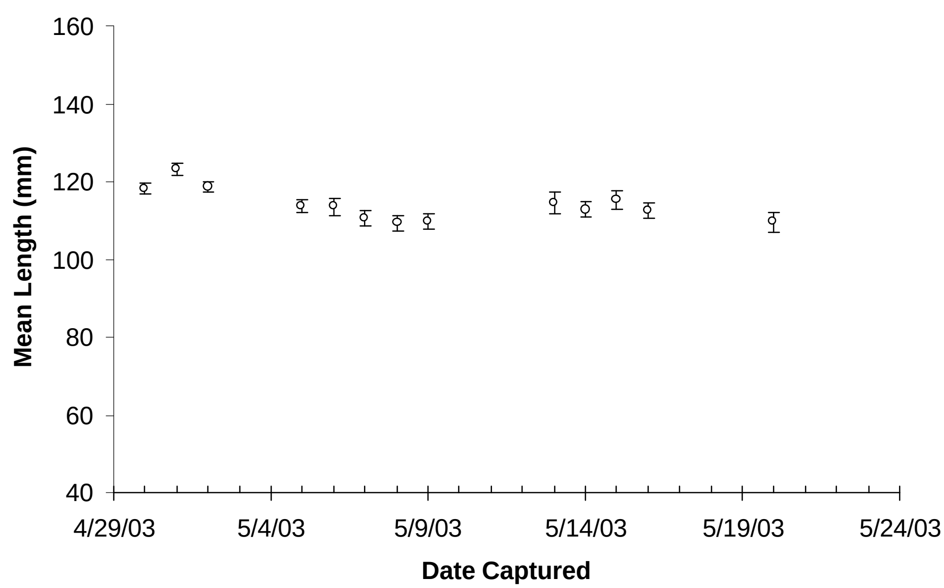


Figure 3-11. Cumulative frequency distributions of lengths of tagged and detected coho salmon caught in Bear Creek (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2003 Lake Washington PIT tag study

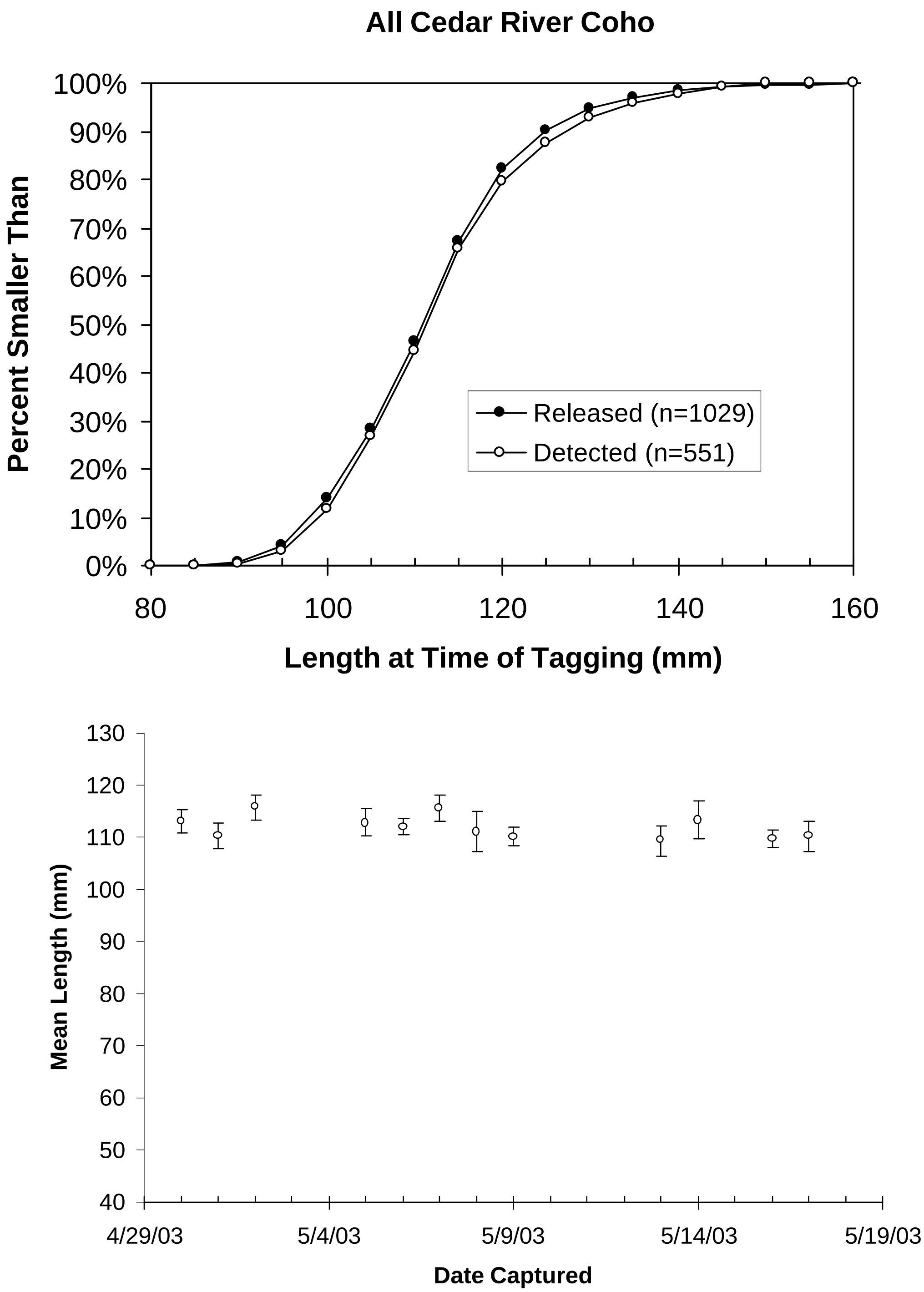


Figure 3-12. Cumulative frequency distributions of lengths of tagged and detected coho salmon caught in the Cedar River (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2003 Lake Washington PIT tag study.

tagged and released on and before May 28, 2003. In contrast, Bear Creek Chinook detected at the Locks after May 28, 2003, were proportionally larger than fish from the total sample released, although the differences were not significant (Figure 3-8). Chi-square test critical á =0.12, 19 classes).

Cedar River Chinook lengths increased at a relatively steady rate until about June 6, 2003, after which rates slowed down (Figure 3-9). A similar temporal difference was seen in the Cedar River Chinook as for Bear Creek when the data were divided into groups tagged before and after June 7, 2003 (Figure 3-10), although the difference was not statistically significant (critical á >0.5, 20 classes, ignoring distribution tail outliers).

Mean lengths of coho salmon smolts remained relatively constant compared with Chinook smolts over the outmigration season in both Bear Creek and the Cedar River (Figures 3-11 and 3-12). There were no significant differences in size distributions of released and detected coho overall (Chi-square test, critical á > 0.5; Figures 3-11 and 3-12).

3.4 MIGRATION BEHAVIOR

The PIT tag data provided valuable information on arrival date and travel rate to the Locks from the different release locations, shoreline affinity behavior, and residualism in Lake Washington. The earlier occurrence of warm water temperatures and reduction in total flume volume may have influenced the total number of Chinook salmon smolts passing through the flumes compared with previous years, although overall detection rates were higher for Bear Creek and Cedar River fish than in 2002 (cf. Table 3-1, comparable table in DeVries 2003; also see Section 4).

3.4.1 Migration Timing

As in 2000, coho salmon generally outmigrated first followed by Chinook salmon (Figure 3-13). The Issaquah Hatchery and Bear Creek Chinook passed through the Locks at about the same time. Similar to 2002, Cedar River Chinook passed later in the season. Conversely, coho salmon juveniles from Bear Creek and the Cedar River passed closer to the same time, although Cedar River fish were again slightly later than Bear Creek fish (Figure 3-14).

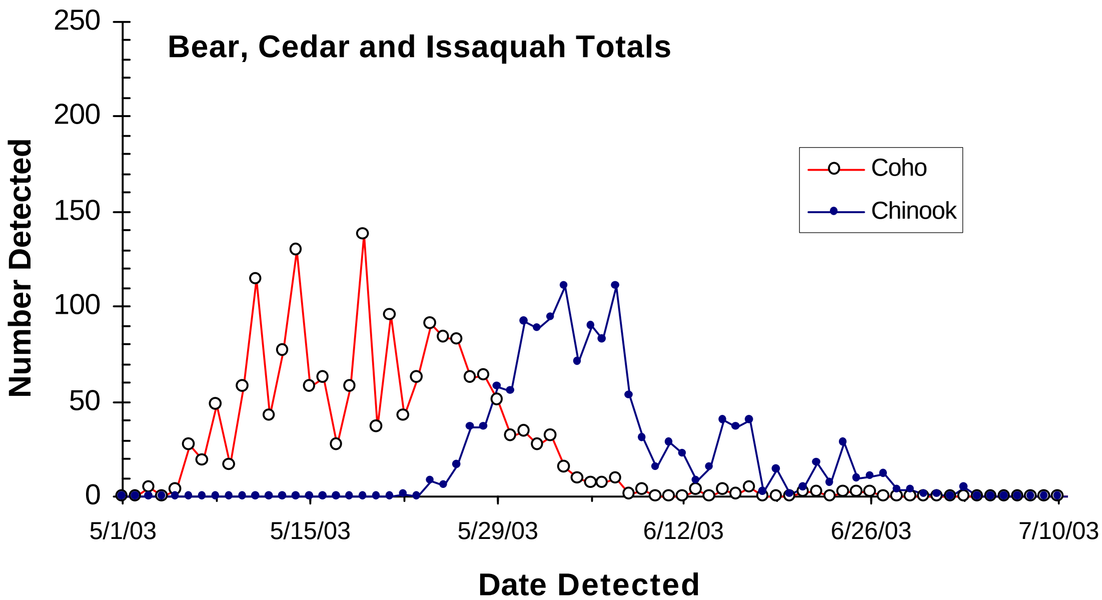


Figure 3-13. Seasonal frequencies of detections at the Locks of Coho and Chinook salmon PIT tagged at Issaquah Hatchery, Bear Creek, and Cedar River, 2003 Lake Washington PIT tag study.

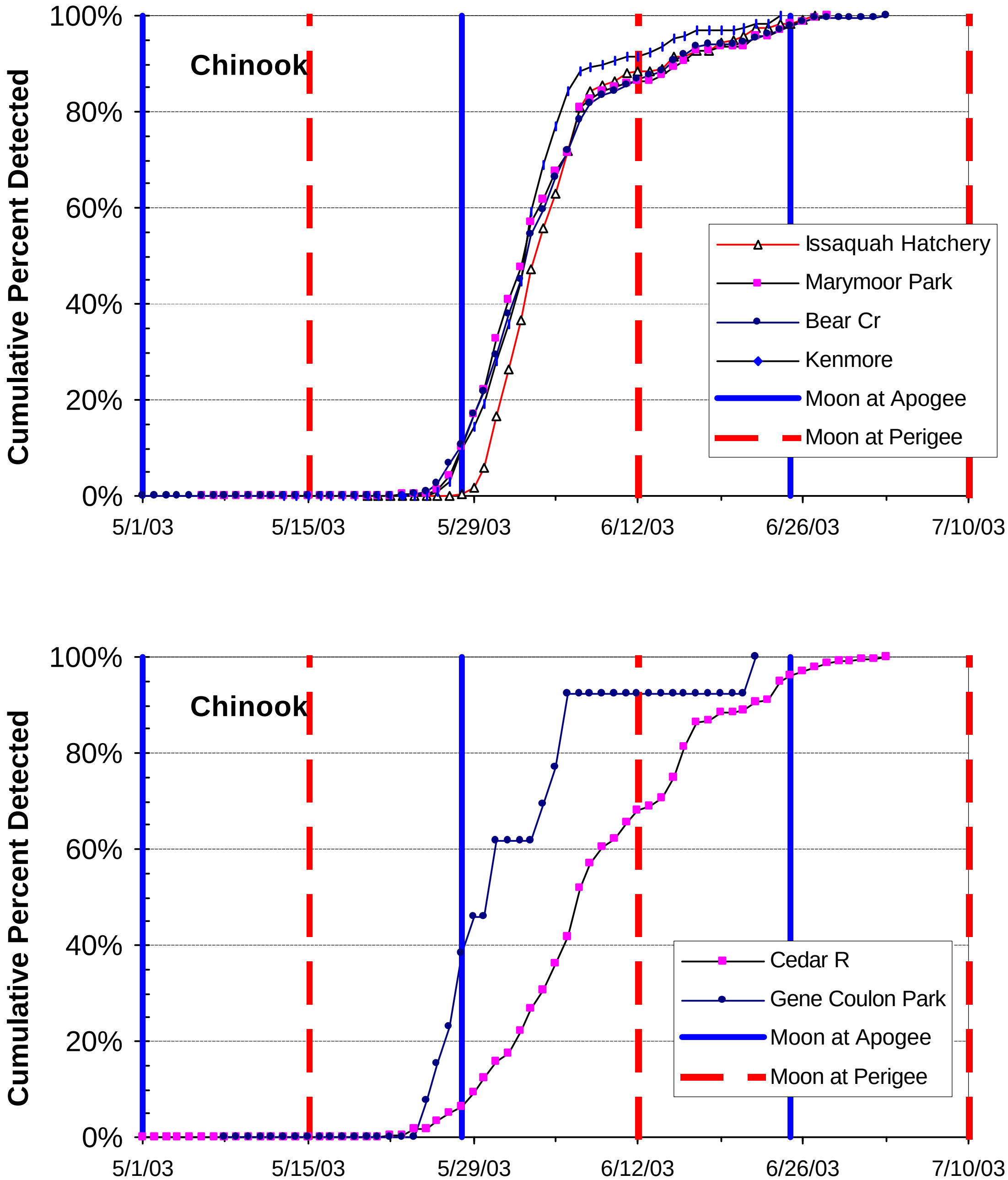


Figure 3-14. Cumulative frequency distributions of the numbers of PIT tagged juvenile Chinook and coho salmon that were detected, as they passed the smolt flumes at the Locks, by date and release location, 2003 Lake Washington PIT tag study. The dates when the moon was at apogee and perigee are indicated by the vertical lines.

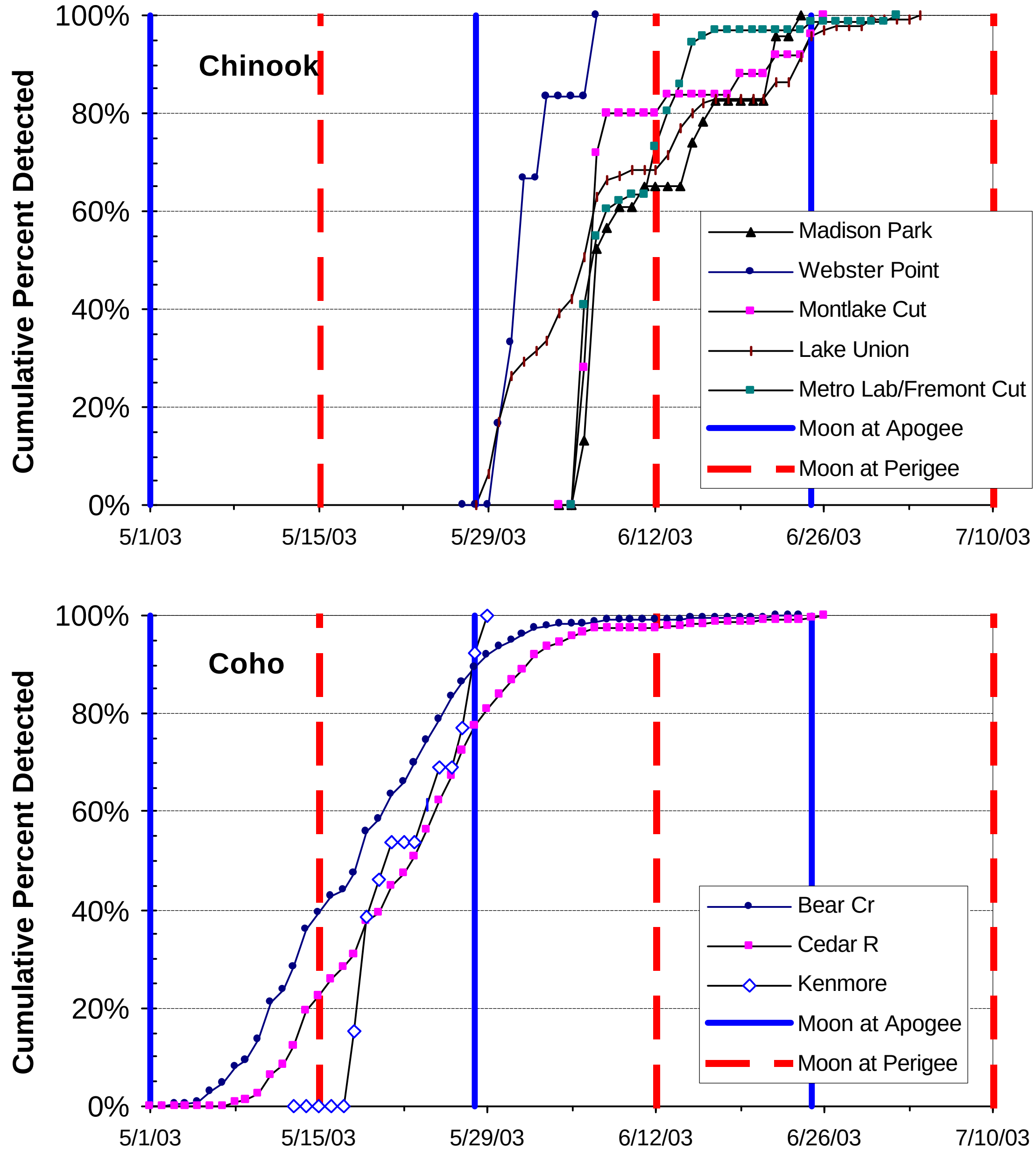


Figure 3-14. (Continued) Cumulative frequency distributions of the numbers of PIT tagged juvenile Chinook and coho salmon that were detected, as they passed the smolt flumes at the Locks, by date and release location, 2003 Lake Washington PIT tag study. The dates when the moon was at apogee and perigee are indicated by the vertical lines.

A comparison of the passage timing data with lunar data indicated passage timing was consistent with patterns observed in previous years, suggesting further that a strong connection existed between moon location relative to the earth and passage timing of Chinook salmon. This connection appeared to be stronger than for new-full moon phasing, which is reasonable considering that light intensity at the Locks at night is strongly influenced by illumination and cloud cover. Specifically, passage through the Locks increased markedly for Chinook salmon within a day or two of the moon being at apogee (i.e., when it is farthest from the earth; Figure 3-14). A weaker trend may have existed for coho salmon. Apogee occurred on May 28 and June 25, 2003. A gravitational influence on passage timing is therefore suggested by the tunnel reader detection data. It is unknown if the fish detect this influence directly, or if it is manifest through other mechanisms.

3.4.2 Migration Rate

Average migration rates varied between the Issaquah Hatchery, Lake Union, Montlake, and tributary release groups. Table 3-2 lists the estimated minimum travel distances between the different release locations and the Locks, excluding possible detours. As in 2002, the number of days between release and detection did not consistently reflect the distance traveled in 2003, which stands in contrast with the first two years of study. Fish released farther away did not always take a longer time to reach and pass the Locks (Figure 3-15). A similar pattern was observed for coho salmon. However, both Chinook and coho salmon juveniles appeared to generally compensate for longer outmigration distances by traveling more rapidly on average (Figure 3-15), which is consistent with the previous three years. The average migration rates reported here are all subject to uncertainty regarding the length of time spent in the vicinity of the Locks before passing through the flumes. For example, if tagged fish spend more than a few days near the Locks, their actual migration rate to the Locks would be faster than the rates estimated here.

Figure 3-16 indicates that migration rates of individual Chinook and coho salmon juveniles exhibit an increasing trend with time over the course of the outmigration season. These results are similar to previous years' and suggest further that juvenile salmon in the Lake Washington system speed up their migration as the end of the passage season approaches. The relationship appears to be stronger for Chinook than coho salmon, which pass the Locks earlier (Figure 3-13).

Table 3-2. Approximate minimum travel distances between release locations of PIT tagged fish and the Locks (see Section 2.7.2 for details on how distances were determined).

Release Location	**Distance to Locks (km)**
West of Fremont Bridge (Metro Laboratory)	3.1
Lake Union, Gasworks, North Shore	5.6
Lake Union, Gasworks, South Shore	5.8
East of Montlake Cut	10
Webster Point	12
Madison Park	13
Magnuson Park	16
Kenmore	27
Cedar River/Gene Coulon Park	39
Bear Creek/Marymoor Park	56
Issaquah Creek	76

The cumulative frequency distributions of numbers of juvenile salmon tagged and detected at the flumes can also be used to describe travel times for the different release groups (Figure 3-17). In general, the distributions indicate that Chinook salmon originating in Bear Creek and the Cedar River took approximately 2 weeks on average to reach and pass the smolt flumes, similar to 2002 results.

Freshwater recaptures at the screwtraps were greater in number in 2003 than previous years (Table 3-3). Most were Chinook and coho salmon recaptured in Bear Creek, and few fish were recaptured more than one day after tagging. Four Chinook and one coho salmon smolts were also recaptured between their original release location and the Locks, providing data on growth and migration rates over increments of the outmigration route (Table 3-4). One Chinook took about a day to migrate from the Issaquah Hatchery through Lake Sammamish, and another a day from the Bear Creek trap through the Sammamish River.

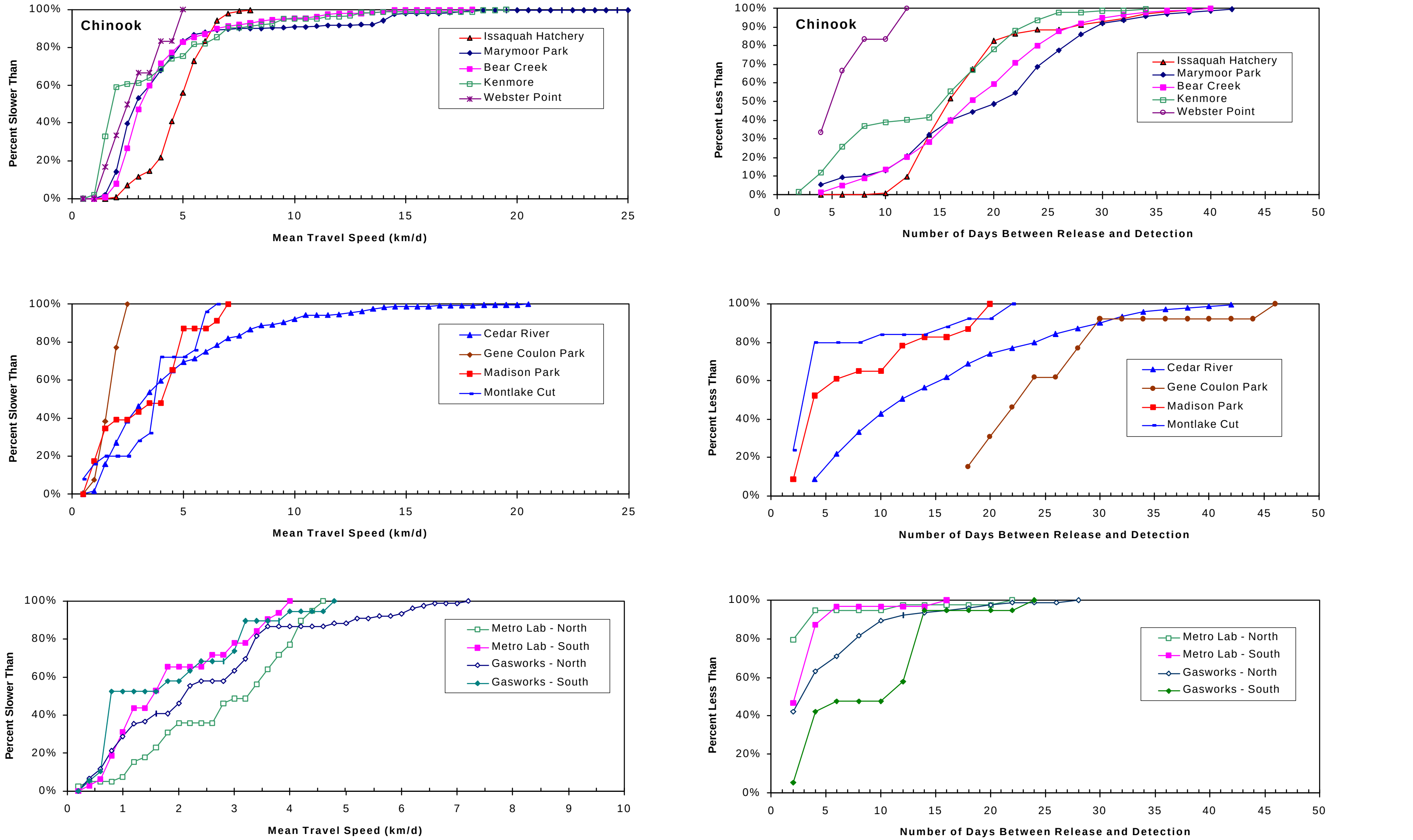


Figure 3-15. Cumulative frequency distributions of average travel speed (left) and time (right) of PIT tagged juvenile Chinook (this page) and coho and sockeye salmon (next page) detected in the smolt flumes at the Locks, by release location, 2003 Lake Washington PIT tag study.

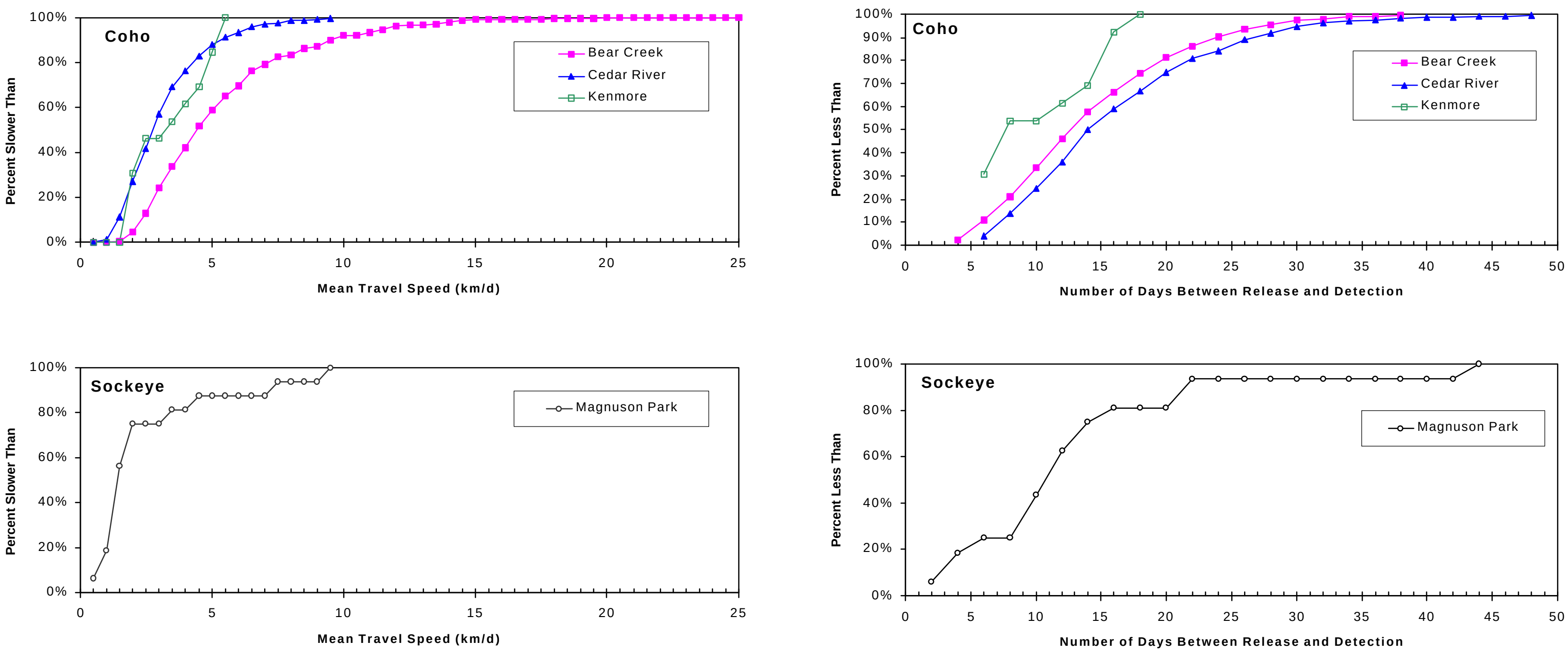


Figure 3-15. (Continued) Cumulative frequency distributions of average travel speed (left) and time (right) of PIT tagged juvenile Chinook (this page) and coho and sockeye salmon (next page) detected in the smolt flumes at the Locks, by release location, 2003 Lake Washington PIT tag study.

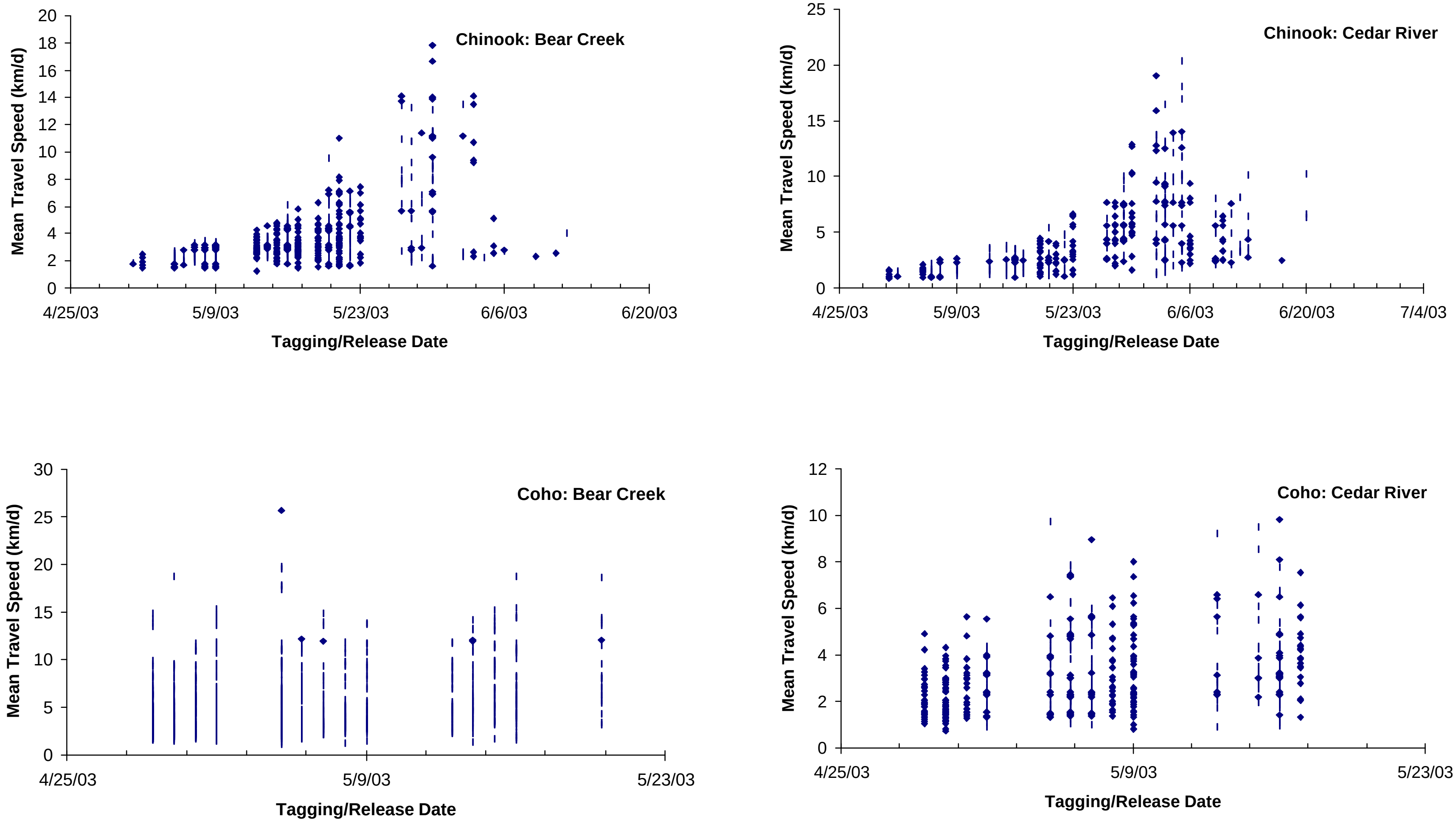


Figure 3-16. Scatterplot of mean travel speed of individual PIT tagged juvenile Chinook and coho salmon that were detected as they passed the smolt flumes at the Locks, plotted by release date and location, 2003 Lake Washington PIT tag study.

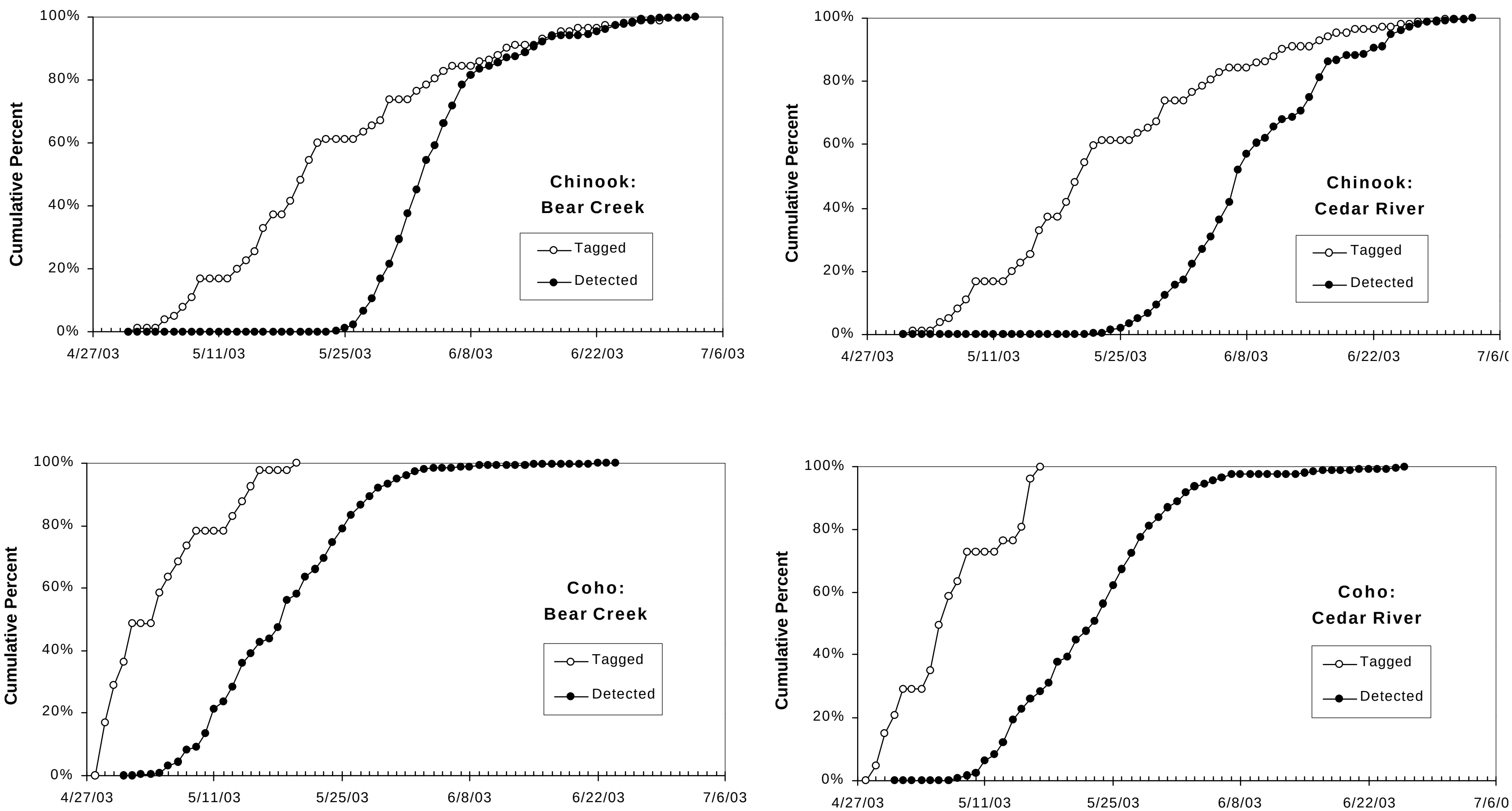


Figure 3-17. Cumulative frequency distributions of the numbers of PIT tagged juvenile Chinook and coho salmon that were tagged and detected as they passed the smolt flumes at the Locks, by date and release location, 2003 Lake Washington PIT tag study. The horizontal difference between the two curves in each plot reflects the average time taken by all fish from a release location to travel to the Locks and pass through the smolt.

Table 3-3. Fish[1] recaptured in screw traps in 2003.

Species	Location	Length (mm) Tagging	Recapture	Date of Tagging	Recapture	Interval (Days)	Detection Date at Locks
Chinook	Bear Cr	85	82	5/14/03	5/15/03	1	5/31/03
"	"	83	nm	5/15/03	5/16/03	1	Not Detected
"	"	90	nm	5/20/03	5/21/03	1	5/31/03
"	"	84	nm	5/20/03	5/21/03	1	6/3/03
"	"	87	nm	5/21/03	5/22/03	1	Not Detected
"	"	85	nm	5/22/03	5/23/03	1	6/22/03
"	"	92	nm	6/12/03	6/13/03	1	Not Detected
"	"	74	nm	6/16/03	6/17/03	1	Not Detected
"	Cedar R	78	79	5/5/03	5/6/03	1	Not Detected
"	"	83	87	5/6/03	5/7/03	1	Not Detected
"	"	91	nm	5/22/03	5/23/03	1	5/30/03
"	"	94	nm	5/22/03	5/23/03	1	Not Detected
Coho	Bear Cr	118	122	4/29/03	4/30/03	1	5/6/03
"	"	123	125	4/29/03	4/30/03	1	5/14/03
"	"	106	109	4/29/03	4/30/03	1	5/14/03
"	"	120	121	4/29/03	4/30/03	1	5/15/03
"	"	112	112	4/29/03	4/30/03	1	5/16/03
"	"	100	100	4/29/03	4/30/03	1	5/29/03
"	"	117	120	4/29/03	4/30/03	1	5/30/03
"	"	117	125	4/29/03	5/1/03	2	Not Detected
"	"	120	119	4/30/03	5/1/03	1	5/17/03
"	"	105	103	4/30/03	5/1/03	1	5/19/03
"	"	104	114	4/30/03	5/1/03	1	5/24/03
"	"	110	114	4/30/03	5/1/03	1	Not Detected
"	"	107	116	4/30/03	5/1/03	1	Not Detected
"	"	122	117	4/30/03	5/1/03	1	Not Detected
"	"	114	117	4/30/03	5/1/03	1	Not Detected
"	"	129	nm	5/1/03	5/2/03	1	5/8/03
"	"	126	125	5/1/03	5/2/03	1	5/8/03
"	"	118	126	5/1/03	5/2/03	1	5/10/03
"	"	116	115	5/1/03	5/2/03	1	5/10/03
"	"	119	116	5/1/03	5/2/03	1	5/14/03
"	"	115	114	5/1/03	5/2/03	1	5/14/03
"	"	139	122	5/1/03	5/2/03	1	5/21/03
"	"	127	129	5/1/03	5/2/03	1	5/22/03
"	"	115	116	5/1/03	5/2/03	1	Not Detected
"	"	112	111	5/1/03	5/2/03	1	Not Detected
"	"	118	113	5/5/03	5/6/03	1	Not Detected
"	"	99	101	5/8/03	5/9/03	1	5/26/03
"	"	107	107	5/13/03	5/16/03	3	5/25/03

Table 3-3. Fish[1] recaptured in screw traps in 2003.

Species	Location	Length (mm) Tagging	Recapture	Date of Tagging	Recapture	Interval (Days)	Detection Date at Locks
"	"	118	118	5/13/03	5/14/03	1	6/3/03
"	"	117	117	5/13/03	5/14/03	1	Not Detected
"	"	108	108	5/13/03	5/14/03	1	Not Detected
"	"	126	126	4/29/03	4/30/03	1	} 5/11/2003; Same Fish
"	"	126	130	4/30/03	5/1/03	1	
"	"	125	127	4/29/03	4/30/03	1	} 5/14/2003; Same Fish
"	"	127	141	4/30/03	5/1/03	1	
"	"	128	129	4/29/03	4/30/03	1	} Not Detected; Same Fish
"	"	129	128	4/30/03	5/1/03	1	
"	"	127	126	4/30/03	5/1/03	1	} 5/11/2003, Same Fish
"	"	126	128	5/1/03	5/2/03	1	
"	"	145	143	4/30/03	5/1/03	1	} Not Detected; Same Fish
"	"	143	147	5/1/03	5/2/03	1	
"	"	97	97	5/14/03	5/15/03	1	} Not Detected; Same Fish
"	"	97	nm	5/15/03	5/16/03	1	
"	Cedar R	119	nm	5/16/03	5/17/03	1	5/23/03
"	"	110	nm	5/16/03	5/17/03	1	5/28/03
"	"	120	119	5/5/03	5/6/03	1	5/23/03
"	"	117	117	4/29/03	4/30/03	1	Not Detected
"	"	113	112	5/6/03	5/7/03	1	Not Detected
"	"	117	115	5/6/03	5/7/03	1	Not Detected
"	"	120	nm	5/16/03	5/17/03	1	Not Detected

[1] *- All had adipose fins intact.*

Table 3-4. Summary of 2003 freshwater PIT tag recapture data in the Lake Washington system.

		Location of:		Migration Between Release and Recapture Locations					Subsequent Migration to Locks	
Species	**Origin**	**Tagging/Release**	**Recapture**	**Release Date**	**Days to Recapture**	**Approx. Travel Distance (km)**	**Average Migration Rate (km/d)**	**Average Growth Rate (mm/d)**	**Days**	**Average Migration Rate (km/d)**
Chinook	W	Bear Creek	Kenmore	05/29/03	1.0	29	29.6	0.0	14	1.9
"	H	Issaquah Hatchery	Marymoor Park	05/19/03	0.9	20	22.3	na	*Not Detected at Locks*	
"	H	Marymoor Park	Webster Point	05/20/03	7.4	44	5.9	0.5	*Not Detected at Locks*	
"	W	Cedar River	Lake Union	05/30/03	12	33	2.7	0.4	*Not Detected at Locks*	
Coho	W	Bear Creek	Kenmore	05/05/03	7.9	29	3.7	0.6	15	1.8

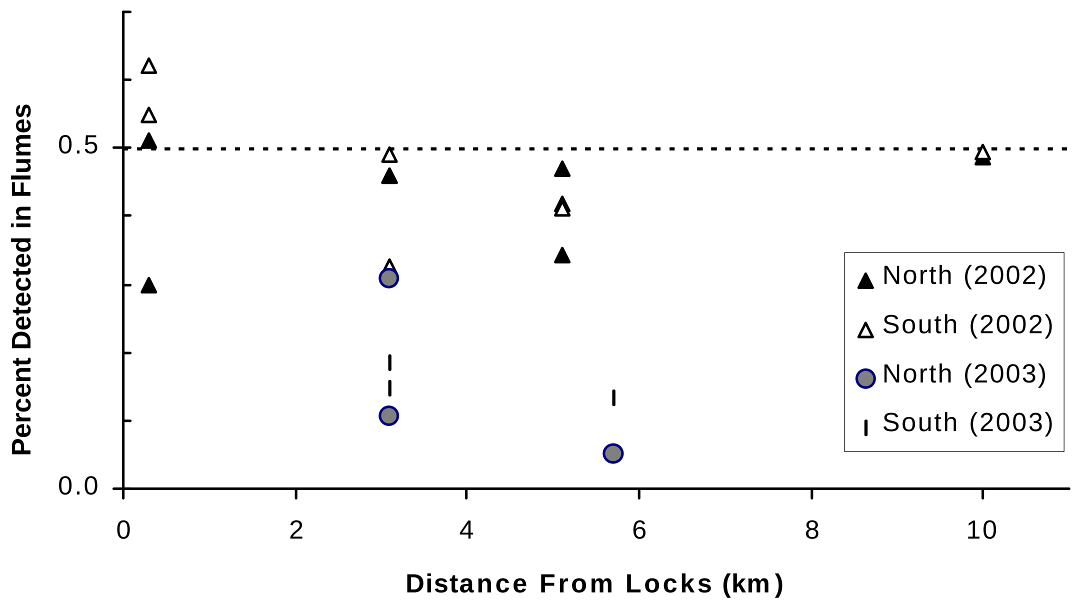
3.4.3 Shoreline Affinity in LWSC and Lake Washington

The 2003 PIT tag study placed less effort on testing shoreline affinity of smolts in Lake Washington and the LWSC than the 2002. Nonetheless, the 2003 results corroborate and add to the previous year's data. The proportion detected in the flumes was lower in 2003 than in 2002 for both the north and south shore releases. This may have reflected the warmer water temperatures in 2003 affecting both the proportion using the flumes and the survival of the tagged fish (Figure 3-18; see Appendix A report and Section 3.6). However, the ratio of south:north detections did not appear to be substantially different from 1.0 for the fish released at the Metro Laboratory, suggesting they were well-mixed by the time both groups reached the Locks. The groups released near Gasworks Park did not follow this trend, where the south shore fish were detected in greater proportion than the north shore fish, suggesting some shoreline affinity on their part (Figure 3-18; see Appendix A). The south shore group took longer to reach the Locks than the north shore groups (Figure 3-15), which likely reflects their swimming along the longer south shoreline (Table 3-2). Similarly, Chinook salmon smolts tagged and released at Gene Coulon Park took longer to reach the Locks than fish tagged in the Cedar River (Figure 3-15), suggesting the former group was composed of fish that had taken a right turn after exiting the river and then proceeded to swim along the eastern shore of Lake Washington.

3.4.4 Residualism in the Lake Washington System

The 2003 study further confirmed the hypothesis indicated by the 2002 data and suggested by length frequency data collected in the 2000 and 2001 studies, where some outmigrants may remain in Lake Washington or Lake Union as yearlings before entering saltwater. As in 2002, one natural Chinook detected in 2003 was tagged two years earlier, although its reported length at the time of tagging may have been an error (131 mm, which is generally larger than the typical range of young of year Chinook in the system; Table 3-5). Two other Chinook and two coho salmon yearlings were also detected. Comparisons of the fish length and tagging date data in Table 3-5 with length frequency distributions in 2000 and 2001 indicated that three of the residualized fish were from the smaller half of the size distribution.

In addition, four fish of unknown origin were detected in 2003. These could have been from 2001 or 2002 based on tag number sequencing, or from another study. The tags were not registered in the PTAGIS database.



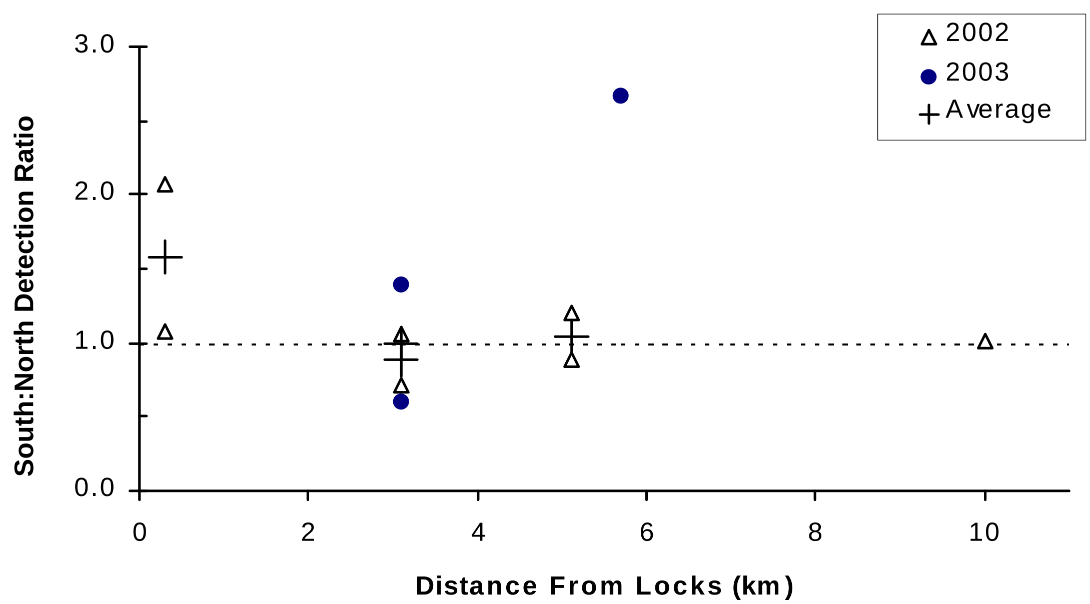


Figure 3-18. Top: Proportion of fish released along the south and north shore that passed through the smolt flumes, 2003 Lake Washington PIT tag study. The 2002 study results are also presented for comparison. Numbers have been adjusted to account for flume detection efficiencies. Bottom: Ratio of numbers of fish released along the south shore to numbers of fish released at the same time along the north shore; average values are depicted by the '+'.

Table 3-5. Fish detected at the Locks in 2003 but tagged in 2002 or 2001.

Species	Tagging Length (mm)	Release Location	Release Date	Flume Detection Date	Flume Detection Time	Interval (Days)
Chinook	131	Cedar River	7/4/01	5/24/03	9:10:27	689
"	76	Issaquah Hatchery	5/31/02	6/8/03	11:29:29	373
"	70	"	5/31/02	6/5/03	5:33:13	370
Coho [1]	97	Bear Creek	6/14/02	5/9/03	13:47:16	329
" [1]	124	"	6/21/02	5/16/03	7:56:57	329
Unknown	Unknown	Unknown	2001 or 2002 [2]	5/25/03	15:45:32	na
"	"	"	2001 or 2002 [2]	6/2/03	17:01:32	"
"	"	"	2001 or 2002 [2]	6/7/03	6:56:48	"
"	"	"	2001 or 2002 [2]	6/26/03	12:40:40	"

1 - Adipose fins intact.

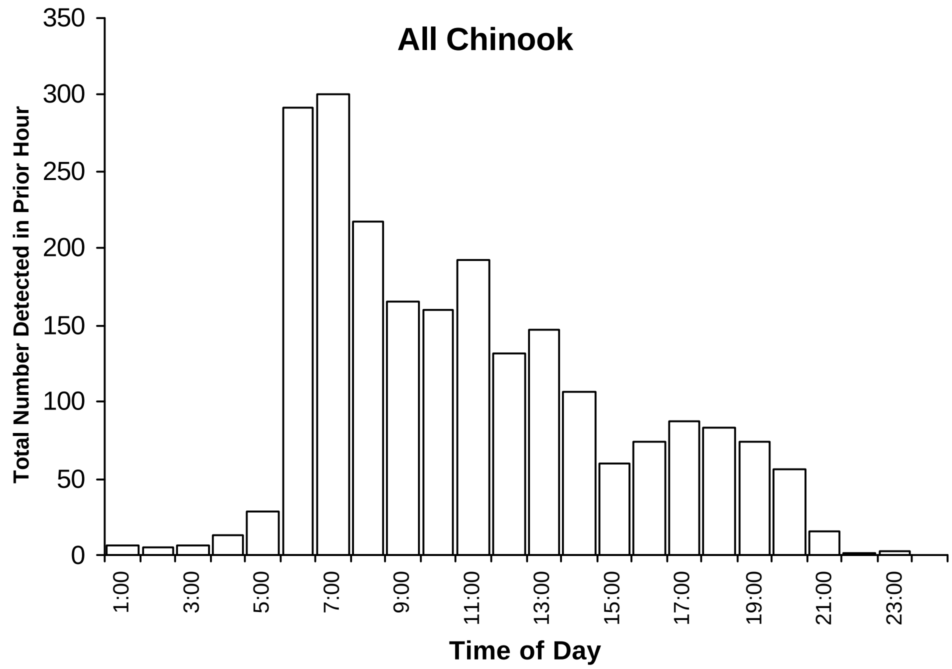
2 - Based on tag number sequencing

3.5 PASSAGE BEHAVIOR AT LOCKS

The PIT tag data also provided valuable information on the daily timing and routes of downstream passage at the Locks, as well as insights into possible influences of lock operations on passage behavior.

3.5.1 Diurnal Variation in Passage Timing

As in previous years, a behavioral pattern that was common to all release groups was the predominance of passage during daylight hours (Figure 3-19). Passage rates increased markedly beginning around 5:00 am. Moreover, there were generally two pronounced peak passage times: between approximately 5:00 am and 9:00 am, and between 3:00 pm and 8:00 pm. The second peak occurred much later in the day than in 2001, when it occurred between 11:00 am and 2:00 pm. Issaquah Hatchery Chinook salmon smolts exhibited slightly different hourly passage timing distributions from Chinook tagged and released at the other 2003 study sites (Figure 3-20). Cedar River and Bear Creek coho salmon exhibited similar distributions (Figure 3-20). Both Cedar River and Bear Creek Chinook juveniles took tended to pass slightly earlier in the day than Issaquah Hatchery Chinook (Figure 3-20). These results generally stand in contrast to data collected for the Columbia River system, where passage at hydropower facilities has been noted to occur predominantly during nighttime hours (e.g., Brege et al. 1996).



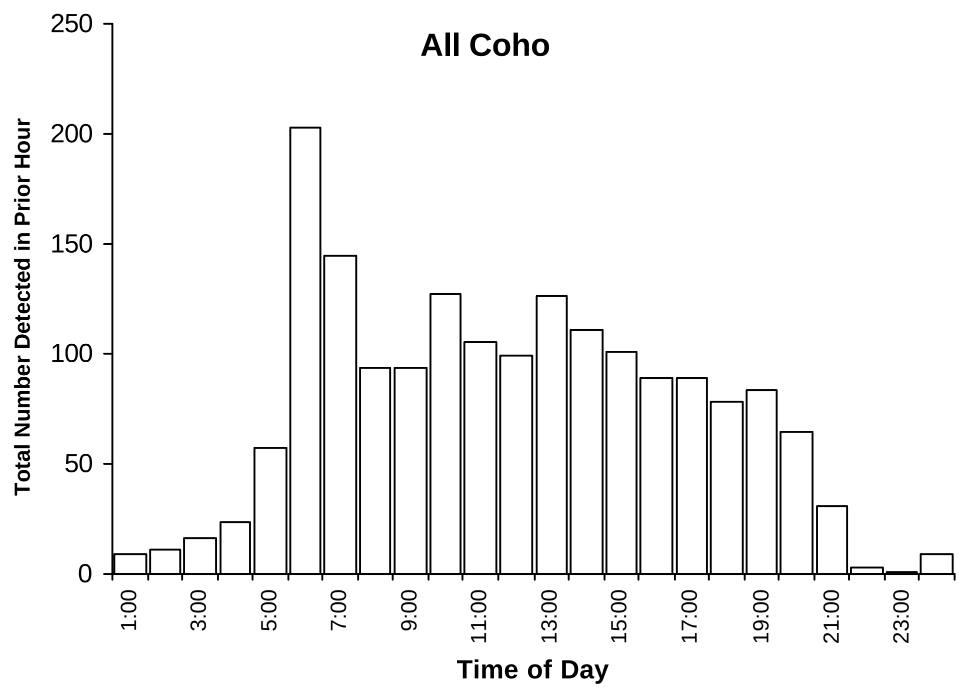
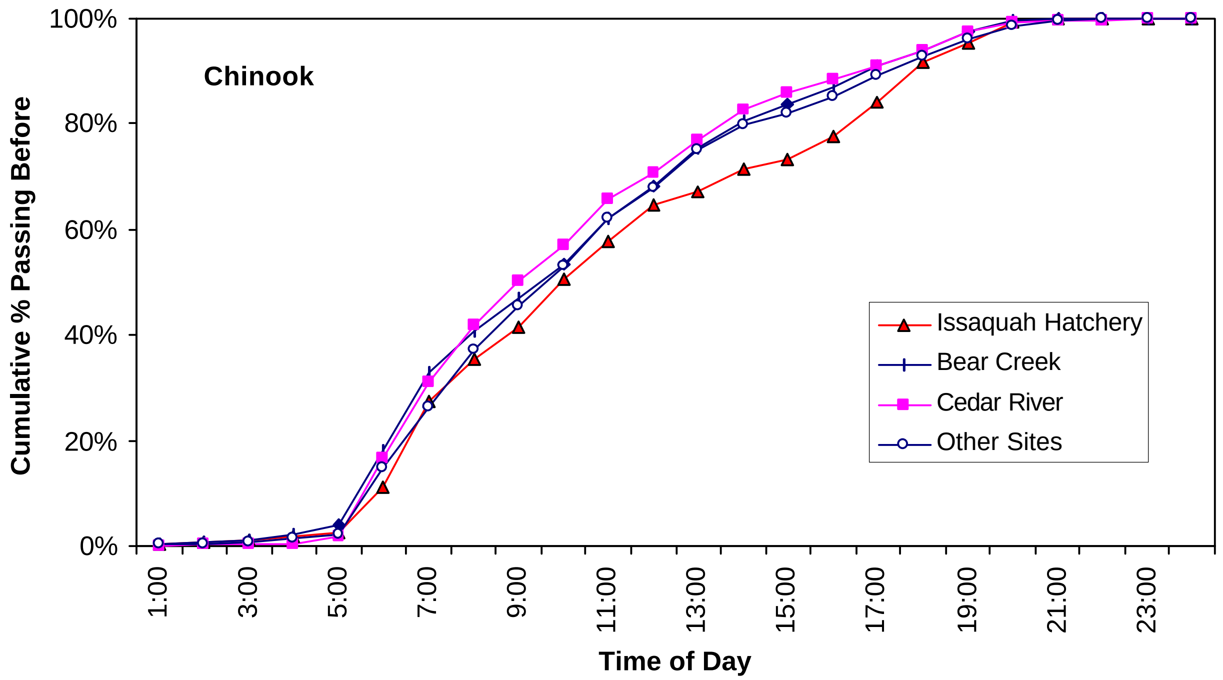


Figure 3-19. Diurnal variation in time of passage through the smolt flumes at the Locks by PIT tagged juvenile Chinook and coho salmon, 2003 Lake Washington PIT tag study. All release groups for each salmon species are represented.



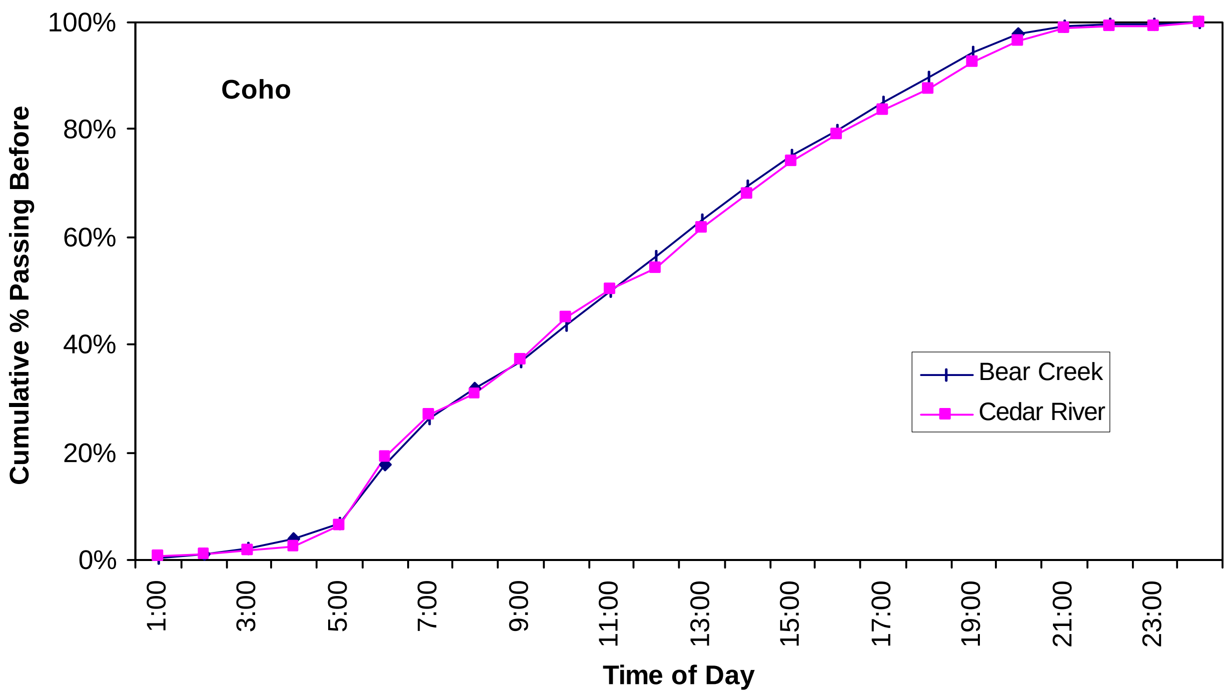


Figure 3-20. Cumulative frequency distributions of the diurnal variation in time of passage through the smolt flumes at the Locks by PIT tagged juvenile Chinook and coho salmon, by release location, 2003 Lake Washington PIT tag study.

3.5.2 Routes Through the Locks

Figure 3-21 depicts the possible passage routes through the Locks. As in previous years, the PIT tag data indicated that recycling occurred through the Locks in 2003, where 32 PIT tagged Chinook salmon and one coho salmon were detected twice by the tunnel readers (Figure 3-22). All fish had to have moved back upstream through either the large or small lock. Another four Chinook salmon were detected three times. As in previous years, most of these were calibration test fish that had been released directly in the flumes, indicating that the method of introduction using a PVC pipe from the walkway probably did not injure the fish as they entered the fast-moving water. The behavior of the calibration test Chinook may have reflected their being held in chilled water and subsequent release directly into the warmer water passing through the flumes.

Recycling rates were an order of magnitude smaller in 2003 than in 2002 and 2001. Of fish originating from Bear Creek, Cedar River, and Issaquah Hatchery, 0.07% and 0.06% of all Chinook and coho detections, respectively, corresponded to recyclers. Recycling rates in 2001 and 2002 were 0.39% and 0.71%, respectively, for Chinook, and 0.70% and 0.50%, respectively, for coho.

Recycling timing patterns appeared to be similar to patterns observed in the previous three years. As in 2002, the one coho detected twice exhibited a shorter recycling time than the Chinook salmon. As in all years, the intervening time between first and second detection shortened as the outmigration season progressed (Figure 3-22). There was no relation of recycling time between detections in the flumes to release group or size of fish at time of tagging, similar to previous years.

Assuming survival to the locks from the Metro Laboratory was nearly 100%, the results in Figure 3-18 suggest an average of approximately 19% of fish outmigrating around mid-June, 2003 used the smolt flumes, and the remainder used the alternate routes depicted in Figure 3-21. This proportion, which is lower than estimated for previous years, likely reflects the reduced number of flumes in operation. Detection rates of groups released approximately 2 weeks earlier (the median travel time to the Locks) in Bear Creek and the Cedar River were generally around 25-40% at this time (see Section 3.6), suggesting that the Metro Lab release groups may also have experienced post-tagging mortality. The detection rate data for Bear Creek and the Cedar River are most likely of all the release groups to be representative of the proportion using the flumes, assuming full mixing in the LWSC.

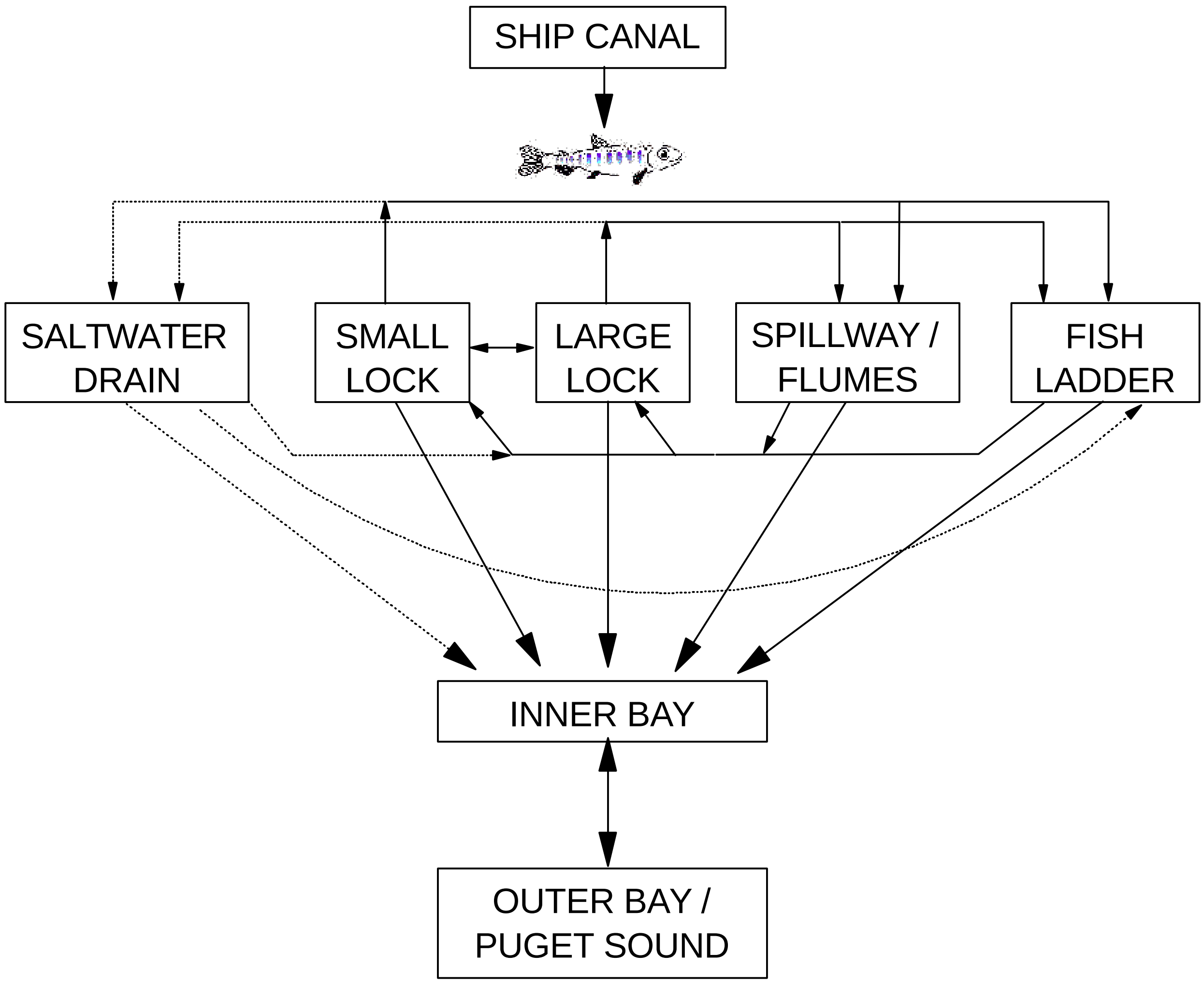


Figure 3-21. Possible migration routes of juvenile salmon through the Hiram M. Chittenden Locks to the Puget Sound. The routes are indicated for fish after they have first encountered the Locks and have entered one of the five structural facilities indicated. For example, a fish entering the smolt flumes may subsequently move back upstream through either the small or large lock, and return downstream through any of the five routes. Alternatively, the fish may migrate directly to saltwater. The route through the saltwater drain is thought to be of lesser importance to smolt passage than the other four routes and is thus indicated by the dashed lines.

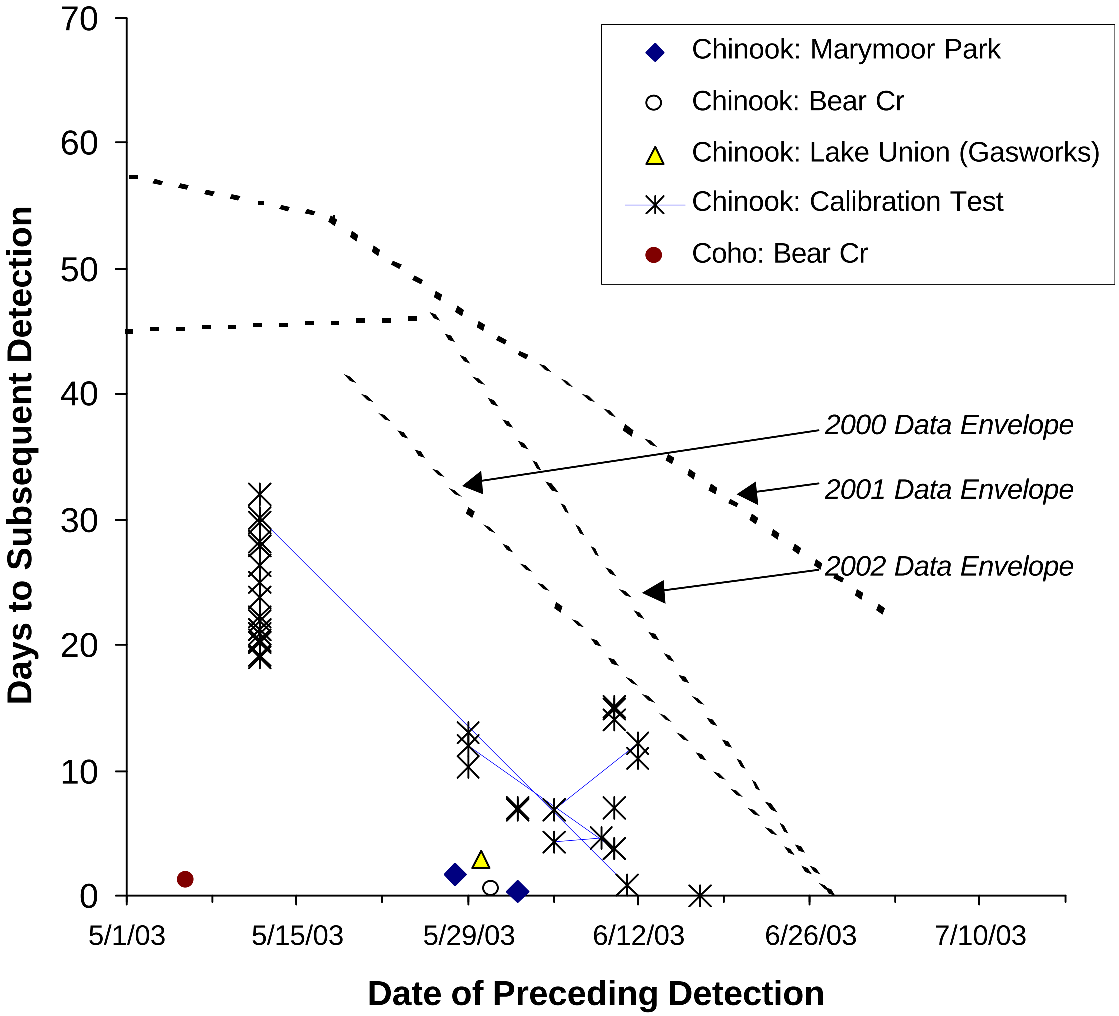


Figure 3-22. Recycling times of PIT tagged juvenile Chinook and coho salmon passing downstream twice through the smolt flumes at the Locks, 2003 Lake Washington PIT tag study. The upper data envelopes from the three previous years are also present for comparison.

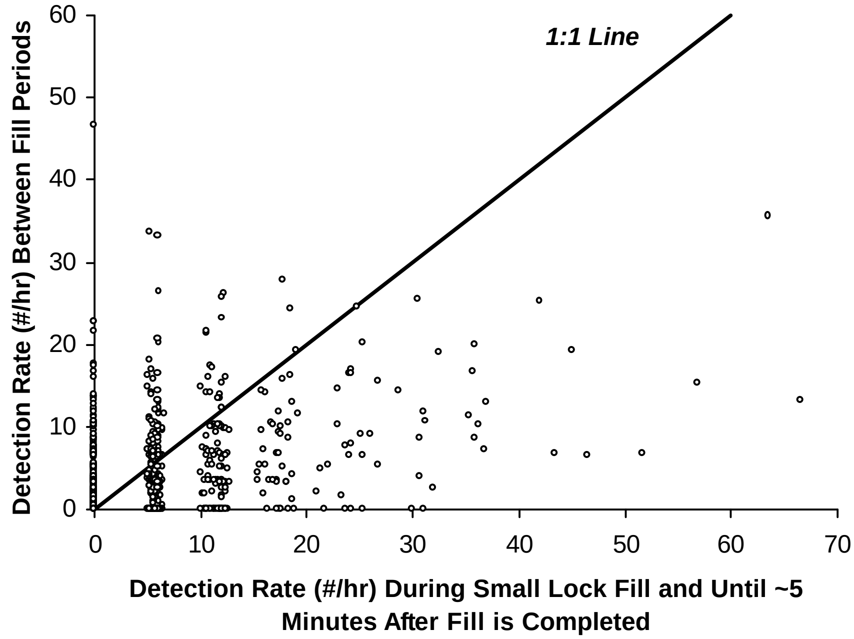
3.5.3 Influence of Lock Operations on Passage Through Flumes

Previous years, results have suggested that passage timing through the flumes is correlated with small lock operations. Figure 3-23 similarly indicates that there was a tendency for PIT tagged fish to pass through the flumes at a higher rate during the small lock fill period than during the between-fill period in 2003. To evaluate this statistically, the data in the figures were filtered and cases identified where fish were detected during consecutive fill and between-fill periods. A ratio was calculated of the passage rate during fill to the passage rate during the subsequent between-fill period. Two-tailed t-tests of the ratio indicated that it was significantly greater than 1.0 on average ($p<0.05$). As in 2001 and 2002, the numbers detected per unit time during fill in 2003 were approximately twice the number between fills on average for each lock. In other words, mean passage rates through the flumes were roughly double while the small lock was filling than when they were not filling.

3.6 DETECTION RATE AND SURVIVAL ESTIMATES

The PIT tag data were used to evaluate temporal variation in detection rates at the smolt flumes and estimate relative differences in survival over discrete segments of the outmigration route in the LWSC and the Lake Washington system. However, the precision of the results was adversely influenced by the variation in tunnel reader detection efficiency, and because the proportion using the flumes could not be estimated consistently nor precisely over the passage season. Previous years' PIT tag data indicated that the proportion using the flumes dropped off during the course of the season. This phenomenon was observed again in 2003 and was consistent for Bear Creek and Cedar River Chinook, and Bear Creek coho salmon juveniles (Figure 3-24). Cedar River Chinook appeared to have a slightly higher detection rate for groups tagged and released in June 2003 (Figure 3-24), suggesting a slightly higher survival rate for that group during that period. Sample sizes were too small for other species to infer trends. Tagging was halted for coho during the third week in May when concerns arose regarding the availability of tags for Chinook. Detection rates held steady for Cedar River coho, but declined over time for Bear Creek coho smolts (Figure 3-24).

Average weekly detection rates (after adjusting for detection efficiency) were on the order of 40% to 60% for Chinook released in Bear Creek and the Cedar River in May and declined to zero for groups released in the third week of June 2003 (Figure 3-25). There were no data later in the outmigration season for inferring trends for coho salmon. The 2003 results were generally consistent with the apparent temporal trend in proportion using the flumes suggested by previous years' data.



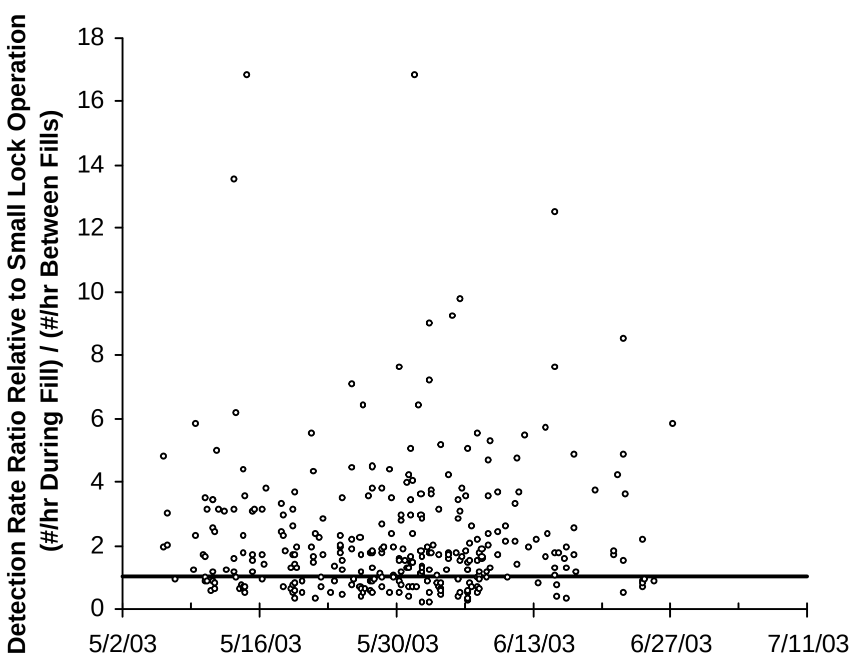
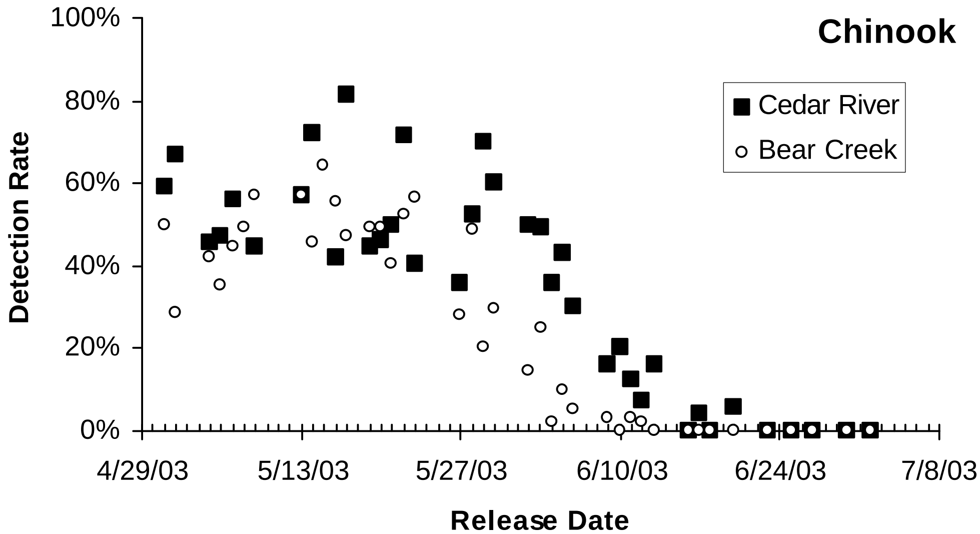


Figure 3-23. Comparison of passage rates of PIT tagged juvenile salmon (all species) through the smolt flumes at the Locks during filling of the small lock and until the next fill, 2003 Lake Washington PIT tag study. The bottom plot shows the ratio of the two passage rates over time. The line of equality is indicated by the solid diagonal (top) and horizontal (bottom) line.



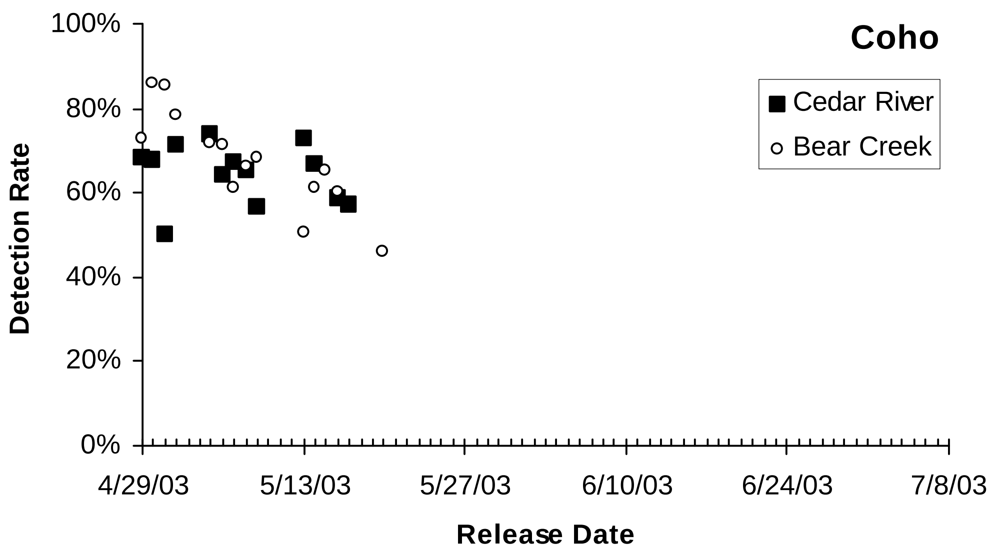


Figure 3-24. Daily variation of detection rate at the smolt flumes of PIT tagged juvenile Chinook and coho salmon originating in Bear Creek and the Cedar River by release date, 2003 Lake Washington PIT tag study. Each data point was calculated by dividing the number released in a group into the number subsequently detected at the Locks, adjusted for detection efficiency.

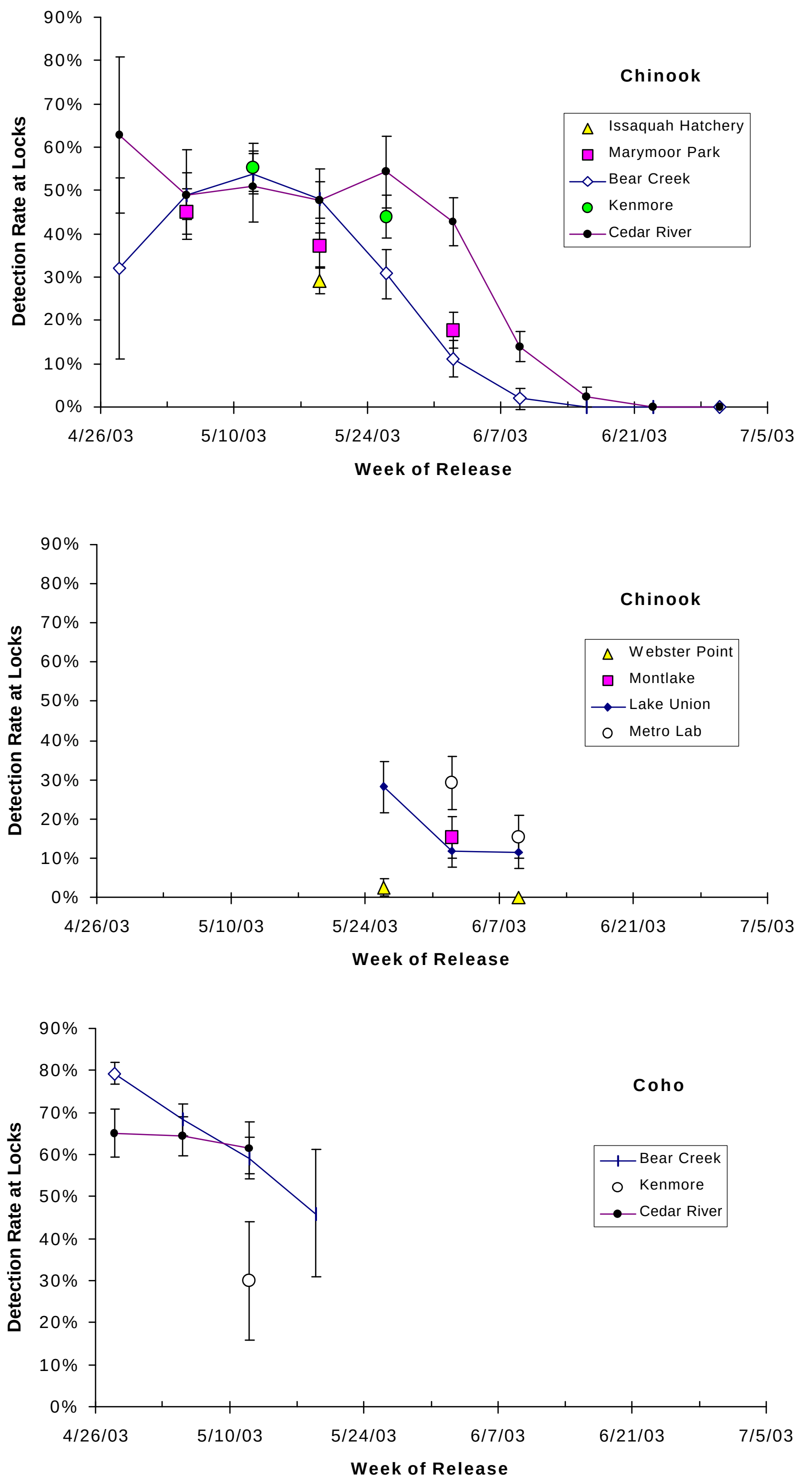


Figure 3-25. Weekly variation of detection rate at the smolt flumes of PIT tagged juvenile Chinook and coho salmon originating in Bear Creek and the Cedar River by release date, 2003 Lake Washington PIT tag study. The data in Figure 3-25 were grouped by week. Ninety-five percent CI are presented based on the binomial approximation for a proportion.

Segment survival estimates appeared most consistent (and thus least biased) based on fish tagged and released at the Issaquah Hatchery, Bear Creek, and the Cedar River (Table 3-6). Minor bias may exist in the estimates for fish tagged and released at Marymoor Park and Kenmore but the extent of bias cannot be quantified. Fish released at the other sites had markedly lower detection rates than would be expected given their greater proximity to the Locks, including especially the releases at the Metro Laboratory (Figure 3-25). Survival estimates were generally not possible based on releases from the other locations depicted in the middle graph of Figure 3-25, because their detection rates were typically lower than for groups released upstream (Table 3-6). Estimates are nonetheless presented when possible in Table 3-6 for completeness. Fish tagged and released in Lake Washington and the LWSC experienced more handling stress than fish tagged and released at the Kenmore or Marymoor Park sites, and thus likely experienced more post-handing mortality (see Appendix A report). Warm water temperatures were also probably a factor at the Kenmore and Marymoor Park sites, but handling stress was much less. The resultant bias in detection rates of fish released in Lake Washington and the LWSC preclude drawing conclusions regarding survival in those segments of the outmigration route. The estimates in Table 3–6 should not be used in population modeling unless the associated error is also propagated through, and it is recognized that they probably do not represent survival over the entire outmigration season.

Table 3-6. Estimated survivals over different segments of the salmon juvenile outmigration route in the Lake Washington system, 2003.

			Estimated Migration Route Segment "Survival"[4]								
Species	**Approximate Week of Detection at Locks**	**Value**	**Issaquah Hatchery - Marymoor**	**Issaquah Hatchery - Bear Creek**	**Issaquah Hatchery - Webster Point**	**Issaquah Hatchery - Lake Union**	**Marymoor - Kenmore**	**Marymoor - Lake Union**	**Marymoor - Metro Lab**	**Webster Point - Lake Union**	**Montlake - Lake Union**
Chinook	5/26/03	Week of Release:[2]					5/5/03				
		U/S group Detection Rate:[3]					45%				
		D/S group Detection Rate:					55%				
		Segment Survival:					**82% (12%)**				
	6/2/03	Week of Release:	5/19/03	5/19/03	5/19/03	5/19/03				5/26/03	
		U/S group Detection Rate:	29%	29%	29%	29%				2.6%	
		D/S group Detection Rate:	37%	48%	2.6%	28%				28%	
		Segment Survival:	**78% (13%)**	**61% (8%)**	***na***	***na***				***9% (8%)***	
	6/9/03	Week of Release:					5/19/03	5/19/03	5/19/03		6/2/03
		U/S group Detection Rate:					37%	37%	37%		15%
		D/S group Detection Rate:					44%	12%	12%		12%
		Segment Survival:					**85% (15%)**	***na***	***na***		***na***

[1] - *Based on median travel time of each release group over season (see text)*

[2] - *At upstream release point*

[3] - *Detection rate at Locks corrected for detection efficiency; U/S = group from upstream release point, D/S = group from downstream release point*

[4] - *Survival estimates in italics were likely affected by unexplained variation including post-handling stress and mortality; numbers in parentheses are approximate 95% confidence intervals; na = estimate not possible because downstream group detection rate < upstream group detection rate.*

Table 3-6. (Continued) Estimated survivals over different segments of the salmon juvenile outmigration route in the Lake Washington system, 2003.

			Estimated Migration Route Segment "Survival"[4]								
Species	**Approximate Week of Detection at Locks [1]**	**Value**	**Lake Union - Metro Lab**	**Bear Creek - Kenmore**	**Bear Creek - Webster Point**	**Bear Creek - Montlake**	**Bear Creek - Lake Union**	**Bear Creek - Metro Lab**	**Kenmore - Montlake**	**Kenmore - Lake Union**	**Kenmore - Metro Lab**
Chinook	5/26/03	Week of Release:[2]	5/5/03								
		U/S group Detection Rate:[3]	49%								
		D/S group Detection Rate:	55%								
		Segment Survival:	***88% (13%)***								
	6/2/03	Week of Release:			5/12/03		5/12/03				
		U/S group Detection Rate:			54%		54%				
		D/S group Detection Rate:			28%		28%				
		Segment Survival:			***na***		***na***				
	6/9/03	Week of Release:	6/2/03%	5/19/03		5/19/03	5/19/03	5/19/03	5/26/03	5/26/03	5/26/03
		U/S group Detection Rate:	12%	48%		48%	48%	48%	44%	44%	44%
		D/S group Detection Rate:	29%	44%		15%	12%	29%	15%	12%	29%
		Segment Survival:	***41% (17%)***	***na***		***na***	***na***	***na***	***na***	***na***	***na***
	6/16/03	Week of Release:	6/9/03%				5/26/03	5/26/03			
		U/S group Detection Rate:	11%				31%	31%			
		D/S group Detection Rate:	16%				11%	16%			
		Segment Survival:	***74% (35%)***				***na***	***na***			
Coho	5/19/03	Week of Release:	5/5/03								
		U/S group Detection Rate:	68%								
		D/S group Detection Rate:	30%								
		Segment Survival:	***na***								

[1] - Based on median travel time of each release group over season (see text)
[2] - At upstream release point
[3] - Detection rate at Locks corrected for detection efficiency; U/S = group from upstream release point, D/S = group from downstream release point
[4] - Survival estimates in italics were likely affected by unexplained variation including post-handling stress and mortality; numbers in parentheses are approximate 95% confidence intervals; na = estimate not possible because downstream group detection rate < upstream group detection rate.

Table 3-6. (Continued) Estimated survivals over different segments of the salmon juvenile outmigration route in the Lake Washington system, 2003.

Species	Approximate Week of Detection at Locks	Value	Estimated Migration Route Segment "Survival"[4]: Lake Union - Metro Lab	Bear Creek - Kenmore	Bear Creek - Webster Point	Bear Creek - Montlake	Bear Creek - Lake Union	Bear Creek - Metro Lab	Kenmore - Montlake	Kenmore - Lake Union	Kenmore - Metro Lab
Chinook	5/26/03	Week of Release:[2]	5/5/03	5/5/03							
		U/S group Detection Rate:[3]	49%	9.1%							
		D/S group Detection Rate:	9.1%	55%							
		Segment Survival:	***na***	***16% (8%)***							
	6/2/03	Week of Release:									
		U/S group Detection Rate:									
		D/S group Detection Rate:									
		Segment Survival:									
	6/9/03	Week of Release:			5/26/03	5/26/03	5/26/03	5/26/03	5/26/03		
		U/S group Detection Rate:			54%	54%	54%	54%	9.1%		
		D/S group Detection Rate:			9.1%	15%	12%	29%	15%		
		Segment Survival:			***na***	***na***	***na***	***na***	***60% (30%)***		
	6/16/03	Week of Release:					6/2/03	6/2/03			
		U/S group Detection Rate:					43%	43%			
		D/S group Detection Rate:					11%	16%			
		Segment Survival:					***na***	***na***			

[1] - *Based on median travel time of each release group over season (see text)*

[2] - *At upstream release point*

[3] - *Detection rate at Locks corrected for detection efficiency; U/S = group from upstream release point, D/S = group from downstream release point*

[4] - *Survival estimates in italics were likely affected by unexplained variation including post-handling stress and mortality; numbers in parentheses are approximate 95% confidence intervals; na = estimate not possible because downstream group detection rate < upstream group detection rate.*

4. DISCUSSION OF 2003 RESULTS AND SYNOPSIS OF 2000-2003 FINDINGS

The results of this study provided important insights supporting, supplementing, and adding to those obtained in previous years' PIT tagging studies regarding mortality, migration, and passage characteristics of tagged fish in the Lake Washington and LWSC system. In whole, the data continue to indicate that PIT tagging is a useful and important tool for evaluating outmigration characteristics and the effects of the Locks on juvenile salmon, which were primary study objectives. The results further permit evaluation of the relation between Locks operations and downstream passage by salmon smolts, identification of potential changes to operations that may reduce the effects or help conserve water in a benign manner, and identifying future studies that may be designed to obtain more complete information on smolt behavior in the system. These issues are discussed below. In addition, the results from all four years of study are evaluated collectively to identify trends and characteristics of migration behavior, survival, environmental conditions, and Locks operations suggested or indicated by the data.

Considerable effort was applied in the 2003 study to estimate migration route segment survivals within Lake Washington and the LWSC. Unfortunately, weather conditions and water availability compromised that portion of the study. Surface water temperatures warmed early in the lake and LWSC and likely adversely affected post-handling survival of fish tagged and released in those two water bodies. The extent to which survival estimates were compromised could not be determined with available data. In addition, detection probabilities at the Locks were reduced compared with previous years because fewer flumes were in operation in 2003, reflecting very low spring tributary inflows into Lake Washington. These factors are discussed in greater detail below.

4.1 PIT TAGGING AND LWGI STUDY OBJECTIVES

The results of this and the preceding year studies indicate that PIT tag technology is a viable technique for addressing LWGI Study objectives. The use of PIT tags has provided extensive data that have increased our knowledge and understanding of behavioral migration ecology of salmon smolts in the Lake Washington basin. Although not necessarily to a high level of precision, and despite the probable influence of warming water temperatures on both detection rates and post-handling survival near the end of the outmigration season, the use of PIT tags has also provided insight into spatial variation in mortality over different portions of the migration route (this issue is discussed in greater detail in Section 4.2). PIT tagging was found to be viable for naturally-reared smolts in tributaries to Lake Washington and for smolts migrating through the LWSC, as long as water temperatures during tagging are generally at or below 17 C.

While the goal of estimating net survival to the Locks was not attained comprehensively during the 2000-2003 LWGI study, the results so far suggest that it may still be possible to estimate this over the course of the migration season if test fish are also released regularly at the Metro Laboratory to estimate the proportion using the flumes as it decreases with time because of increasing water temperatures. Knowledge of the proportion allows estimation of survival from each release point to the Locks. The laboratory facilities include means for regulating water temperature and partially acclimatizing fish for subsequent release. However, to do this properly would require additional investment in adding holding capacity at the laboratory. A minimum estimate of the number of fish needed is around 4000 fish (100 fish on north side of the LWSC, 100 on the south side, and at least 2 days/week to provide minimal replication; releases made over the period May through mid-July, or about 10 weeks).

One important goal of the PIT tagging studies as part of the LWGI was to evaluate the use of hatchery fish in lieu of natural origin fish. Chinook salmon juveniles from the Issaquah Hatchery were observed in 2003 and earlier years to be similar to naturally-spawned Chinook from Bear Creek in terms of migration and passage behavior, and possibly survival to the Locks. The shoreline affinity test fish used in 2002, which were Issaquah Hatchery Chinook held at the Metro Laboratory, exhibited similar behavior and detection rates overall to fish tagged and released upstream. An exception was apparent for the calibration test fish, which exhibited the strongest recycling behavior at the Locks of all groups, but these fish were held and released under the least "normal" conditions of all the hatchery release groups, by being transported to the Locks and then released directly into the flumes without acclimation.

The results also provided important information regarding migration and passage characteristics, as well as evaluating the effects of the LWSC project on hatchery and naturally-produced Chinook and other salmon species, thereby meeting another important goal of the PIT tagging study. The resulting information has led to proposed modifications of operations at the Locks, such as shutting off the flumes at night, and for the season after surface water temperatures in the LWSC reach a specified level, to conserve water.

4.2 MEETING THE ASSUMPTIONS OF PIT TAG BASED SURVIVAL ESTIMATORS

The survival estimates presented in this report must be regarded cautiously, more so than for estimates derived in 2002 and 2001. The proportion using the flumes appeared to have been lower than in previous years because of reduced number of flumes operating in 2003, and the early warming of surface water in the LWSC and Lake Washington. Estimator precision was low relative to the estimate because of the limited sample sizes and numbers of replicates involved. In addition, fish released in the LWSC and Lake Washington likely experienced unquantified post-tagging mortality due to elevated surface water temperatures, which also affected the detection rates at the Locks. It is likely that better results would have been obtained if the spring of 2003 had been cooler and wetter, and surface water temperatures had been closer to average or lower values prior to the end of the Chinook salmon smolt outmigration period. In any case, the results for 2003 suggest that migration route segment survival studies cannot be conducted in the basin at a moderate or high level of precision during years when spring surface water temperatures in Lake Washington and the LWSC exceed suitable tagging temperatures (roughly 17 C based on prior years experience; e.g., DeVries 2002) before a sizeable fraction of the Chinook salmon smolt run has passed the Locks.

There was no spill through other gates in 2003. Spill occurred most extensively in 2002, and also occurred intermittently in 2001 and 2000. Hence, it is possible that a greater proportion of naturally reared Chinook and coho salmon smolts passed through the flumes in 2003 than in preceding years, partially compensating for the reduced number of flumes, as suggested by the PIT tag data (Table 4-1). Decisions based on comparing 2003 detection rates with preceding years' values should therefore be made carefully, considering the number of variables that can influence detection rates (e.g., disease in 2000, cooler temperatures in 2002, lowest flume flows in 2003).

The results nonetheless continue to suggest that differential detection rates can be used to provide an indication of survival between two release locations, assuming similar detection probabilities and more favorable climatic conditions. The present approach appears to generate segment survival estimates of comparable precision that could at least be useful for identifying relative differences in survival along different segments of the outmigration route when post-tagging mortalities can be minimized.

The validity of the similar detection probability assumption depends on whether the two groups move downstream at about the same time and are randomly mixed when they arrive at the Locks (Burnham et al. 1987; Iwamoto et al. 1994). Bias related to distance between two locations (Dauble et al., 1993) appears to be addressable by considering migration rates of two groups passing through the flumes around the same date and back-calculating the appropriate release dates to compare. The shoreline affinity results suggest that there is complete mixing within the

LWSC (see Section 4.4.6). Hence, meeting the assumption of complete mixing in the LWSC appears to be generally feasible, and segment survival estimates should be indicative of overall survival trends, water temperatures willing.

The concern remains regarding release group sample size, which continues to be a statistical, logistical, and financial issue in PIT tagging-based survival studies. The confidence interval estimates depicted in Figure 2-5 indicate that release group sizes larger than about 300 fish should not result in substantial improvements in precision of route segment survival estimates using the equations presented in Section 2.7.4.

Table 4-1. Summary of Releases and Detections of PIT tagged Chinook and coho salmon smolts[1] for major release locations, 2000-2003 Lake Washington GI Study

			Issaquah Creek		Bear Creek		Cedar River	
Quantity	**Species**	**Year**	**Natural**	**Hatchery**	**Natural**	**Hatchery**	**Natural**	**Hatchery**
Number Released	Chinook	2000	226	122	525	--	273	--
		2001	--	4676	2132	--	1550	67
		2002	--	4024	2309	--	814	--
		2003	--	992	2305	--	1726	6
	Coho	2001	--	--	1011	12	1235	--
		2002	--	--	2661	--	1038	--
		2003	--	--	2044	--	1027	--
Percent in Flumes[2]	Chinook	2000	0.004	0.008	0.1	--	0.19	--
		2001	--	0.38	0.13	--	0.29	0.06
		2002	--	0.39	0.32	--	0.21	--
		2003	--	0.28	0.35	--	0.3	0.17
	Coho	2001	--	--	0.47	0	0.49	--
		2002	--	--	0.65	--	0.59	--
		2003	--	--	0.72	--	0.66	--

[1] - Insufficient data for sockeye salmon or steelhead trout
[2] - Adjusted for detection efficiency

In years when migration route segment survivals cannot be estimated with confidence because of excessive temperatures influencing post-tagging mortality, it should still be possible to estimate total survival from the tributaries to the Locks. Although Burnham et al.'s (1987) maximum likelihood estimator is superior statistically for evaluating overall survival compared with the segment survival approach (in part because the error in the individual route segment survival estimates is compounded when they are multiplied, and because of generally negligible bias), the approach has proven impractical in the absence of significant funding because it requires recapture of tagged fish below the locks in sufficient numbers to meet precision requirements. The experience in 2001 indicates such an effort would be logistically difficult (if not impossible given low recapture rates), cost-prohibitive and would likely result in extensive take of listed Chinook salmon smolts through handling mortality and de-scaling (DeVries 2002). For example, sampling was conducted night and day for two days in mid-June 2001, but only 2 PIT tagged Chinook from Bear Creek were caught, as were 16 hatchery Chinook used in a tunnel reader calibration test two weeks earlier. The sample size needed to estimate P_{SF} (and thus survival) on a weekly basis to an asymptotic level of precision was too large to be practical, especially for natural origin fish. The effort would have needed multiple crews operating at the same time, day and night, and could have significantly increased the potential number of fish killed or injured using beach seines. Low recapture efficiency has also been a problem on the Columbia River below Bonneville. Efforts to develop towing assemblies that concentrate fish through an open cod end fitted with a detector (e.g., Ledgerwood et al., 2004) could potentially improve this situation by allowing sampling of large numbers of fish without handling them during detection, but it is unknown if such an approach would be feasible in the close confines below the Locks or if it would stress fish unduly in this setting.

Nevertheless, the difficulties encountered in a warm year such as 2003 indicate the need for alternative strategies for estimating survival of tributary Chinook smolts, and one is suggested by the shoreline affinity test results. Specifically, releases along the north and south shore in the vicinity of the Metro Laboratory may permit an independent determination of the proportion of fish using the smolt flumes. When the ratio of south:north shore release group detection rates is approximately equal to 1.0, indicating complete mixing, then the average of those two detection rates should also approximately equal the proportion using the flumes. For example, a single release of 100 fish could be made periodically at the Metro Laboratory during the outmigration season to estimate the proportion using the smolt flumes as it changes over time, with an approximate precision of P_{sf} +/- 0.1 (Zar 1984, equations 22.26 and 22.27). North and south shore replicates of 100 fish each would increase the accuracy through computation of an average detection rate (cf. Figure 3-18) and also allow evaluation of the mixing assumption. This would facilitate estimating survival over the outmigration/passage season for any release group using the basic group survival equation presented in Section 2.7.4. Up to about 2000 fish can be held in the inside tanks at the Laboratory, and more can be held if outdoor tanks are set up as well. This would allow at least 10 tests, at roughly weekly intervals early in the season, and bi-weekly as water temperatures increase. Future release strategies should be designed accordingly if survival estimates are desired for the entire route. In years with spring LWSC water temperatures at average or cooler levels years, the resulting estimate could also be compared against the geometric sum survival estimate of successive segments by assuming approximately 100% survival from the Metro Laboratory location (supported collectively by the 2000, 2001, and 2002 results).

Use of the Table 3-6 survival estimates in production models such as EDT is not recommended because they are essentially single point values in time with relatively large confidence intervals, and the data to date suggest temporal variation exists over the course of the outmigration season. However, relative differences in migration route segment survival estimates can be useful for guiding future management decisions related to identifying where restoration and recovery efforts should be focused, even if the absolute magnitude of the survival estimate of any given segment is itself in question.

4.2.1 Improving Detection Efficiency at the Locks to Improve Survival Estimates

Detection efficiency of the tunnel readers was comparable to efficiencies determined in 2002. The 2003 study still suffered from the same problems as in previous years regarding structural and hydraulic effects on detection efficiencies and incomplete coverage of all the routes through the Locks. The data again indicate that these may be important precision-related limitations on evaluations of survival through the Locks facilities. The large tunnel readers were still operating below the desired minimum detection efficiency of 95%. Based on tagged fish releases, Flumes 4B and 5B were both operating at an average efficiency of 84%, whereas Flume 5C was operating at 97% efficiency. These values are still high enough, however, that the adjusted detection numbers give assurance that the trends reported here are representative. However, they are sufficiently low for the two larger flumes that they add a level of uncertainty to total survival estimates that is not encountered in other tunnel reader installations. Further structural and hydraulic modifications are recommended.

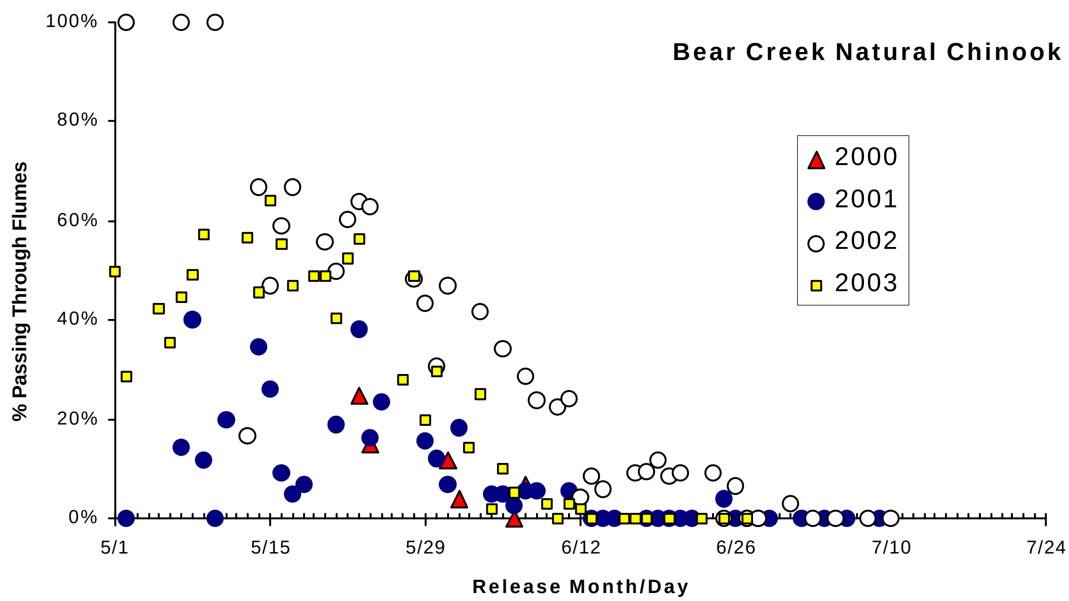
An annually recurring problem has been "pulsing" of water through the flumes at higher lake levels, and development of standing waves. This phenomenon has been manifest by periodic overtopping of the flume sides near the tunnel reader throats, and a visual pulse in the outfall discharge rate. Flow pulsing has occasionally resulted in the ejection of a calibration test fish stick out of the flume before it entered the tunnel reader. Fish have not been observed to have been ejected over the four years of study, and may not be as susceptible as sticks because they appear to swim near the bottom as they are drawn into the flume throat, whereas the sticks float on the surface. However, pulsing and overtopping are associated with intense turbulence at the flume throat entrance, which may have contributed to lower detection efficiency by orienting some fish and fish sticks closer to perpendicular to the long axis of the flume, a sub-optimal orientation. Modification of the flume geometry appears necessary to result in a smoother hydraulic transition leading into the tunnel readers.

An encouraging result of the 2003 study was observed in the calibration testing, in which it was determined that the newer "supertags" were consistently associated with higher detection rates than the standard tags. Future tag purchases should be of the newer, more efficient tags when the flumes at the Locks are used as the primary detection point.

4.2.2 Possible Influence of Water Quality on Survival and Passage at Locks

The data collected between 2001 and 2003 indicate that the proportion of smolts using the flumes changes with time. Detection rates appear to hold steady for tagged Chinook and coho salmon groups released in tributaries in May, and begin declining for groups released in early to mid-June (Figures 4-1 and 4-2). Based on travel time distributions, this corresponds to a decline in detection rates beginning roughly in the third or fourth week of June depending on the year. A review of available water quality data for all four years suggests that the change may be due to changes in water temperature, where surface water temperatures in the LWSC generally reach adverse levels sooner in the outmigration season than near-bottom temperatures. Hence the decrease in detection rates over time could reflect a shift in passage behavior where the outmigrants gradually seek deeper routes through the LWSC and Locks. Passage later in the season would most likely occur via the large lock, the sill elevation of which is 20 feet below that of the small lock on the lake side and approximately 36 feet below the flume entrances.

Water quality data collected by the USACE in the LWSC in 2000 through 2003 support this hypothesis. Figure 4-3 shows that water temperatures in 2003 climbed continually during the study without leveling out. In most locations, the mid-column water temperature was approximately 1-2ºC cooler than the surface temperature. Water temperatures below the Locks are also much cooler, and salt water wedges intruding upstream through the large and small locks would result in cooler, brackish water near the bottom that the smolts may be attracted to as the surface water warms in the LWSC. Water temperatures in the large lock approached 15ºC around the beginning of June, and 19ºC by the first week of July 2003, slightly earlier than in 2002 (Figure 4-3). These temperatures are of significance because they respectively approximate the limit to optimal juvenile salmon growth, and the approximate onset of feeding inhibition and avoidance during migration (ODEQ 1995; McCullough 1999). Temperature



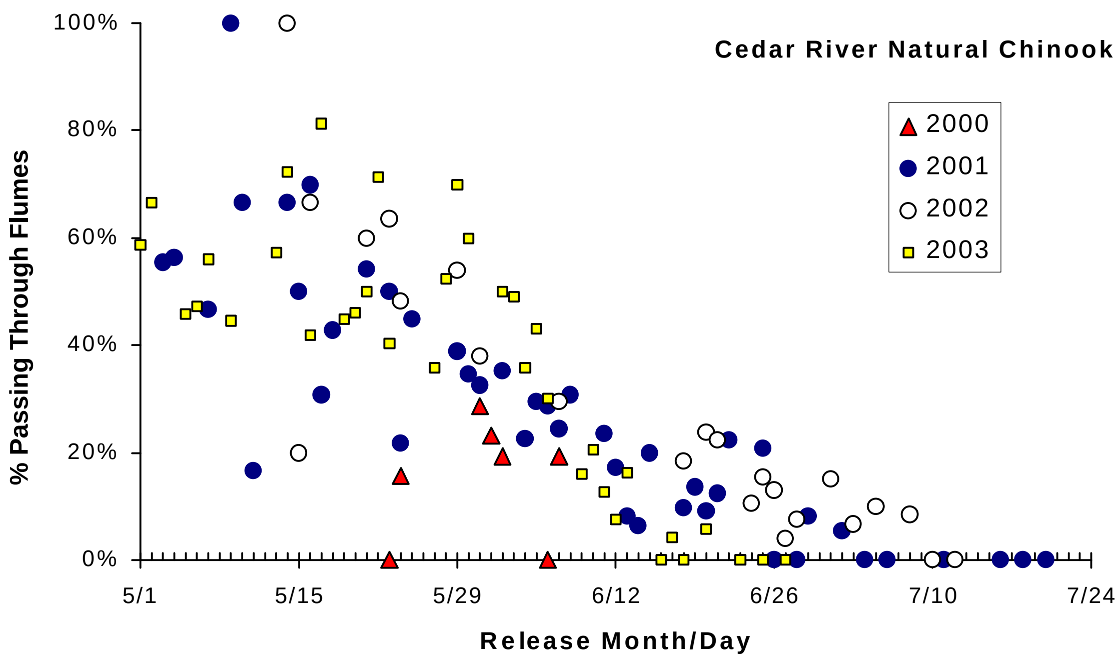
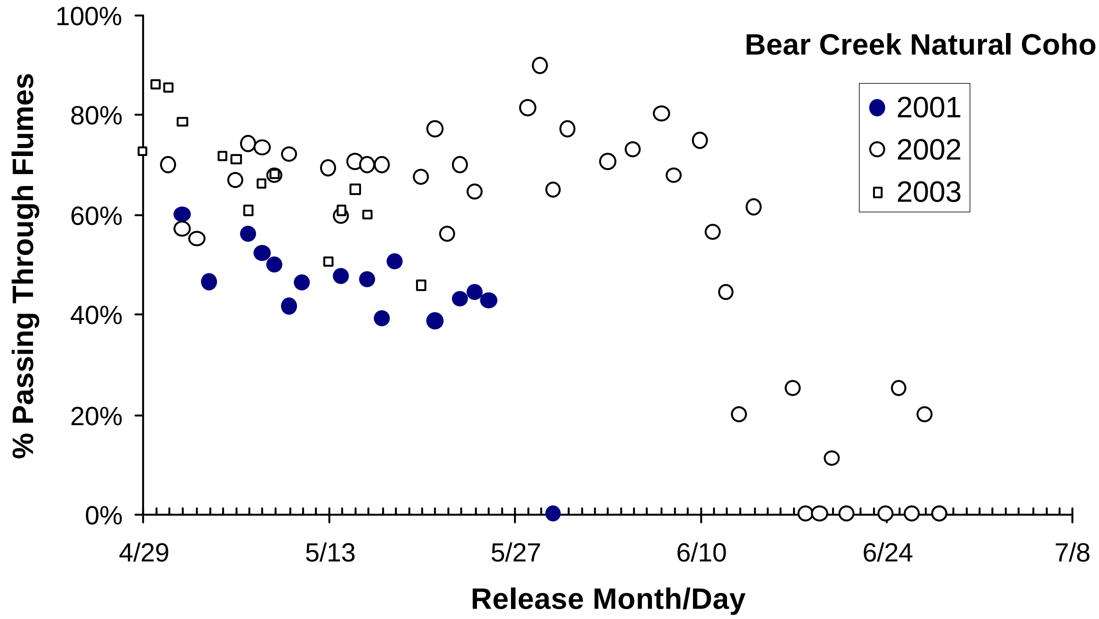


Figure 4-1. Seasonal variation in detection rates in the tunnel readers of juvenile Chinook salmon tagged and released in Lake Washington tributaries, 2000-2003, Lake Washington GI Study. Numbers were adjusted for detection efficiencies.



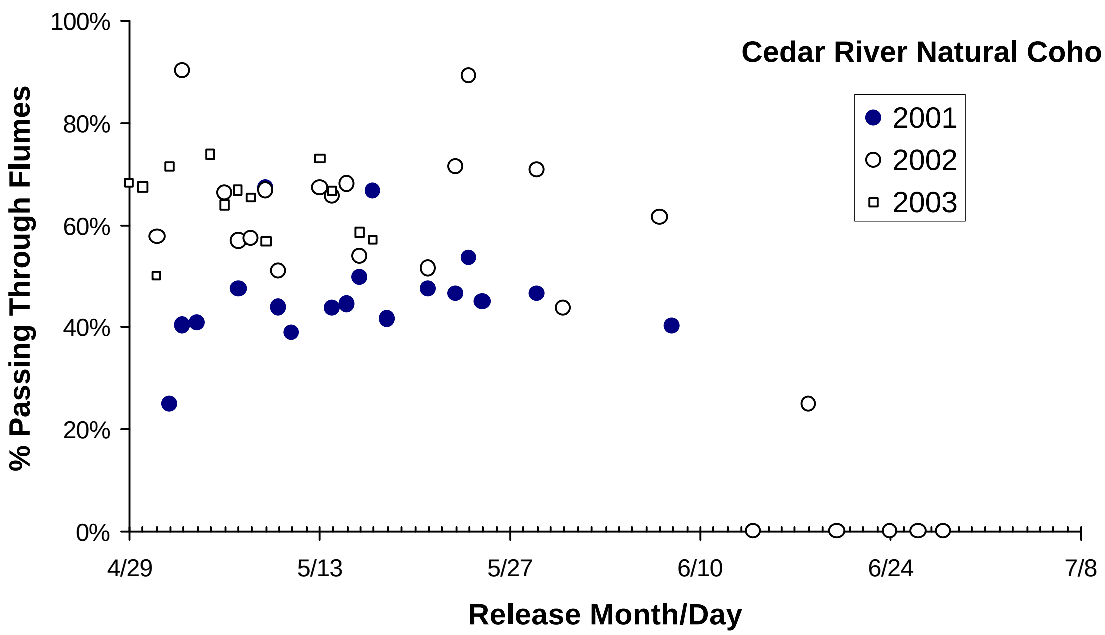


Figure 4-2. Seasonal variation in detection rates in the tunnel readers of juvenile coho salmon tagged and released in Lake Washington tributaries, 2001-2003, Lake Washington GI Study. Numbers were adjusted for detection efficiencies.

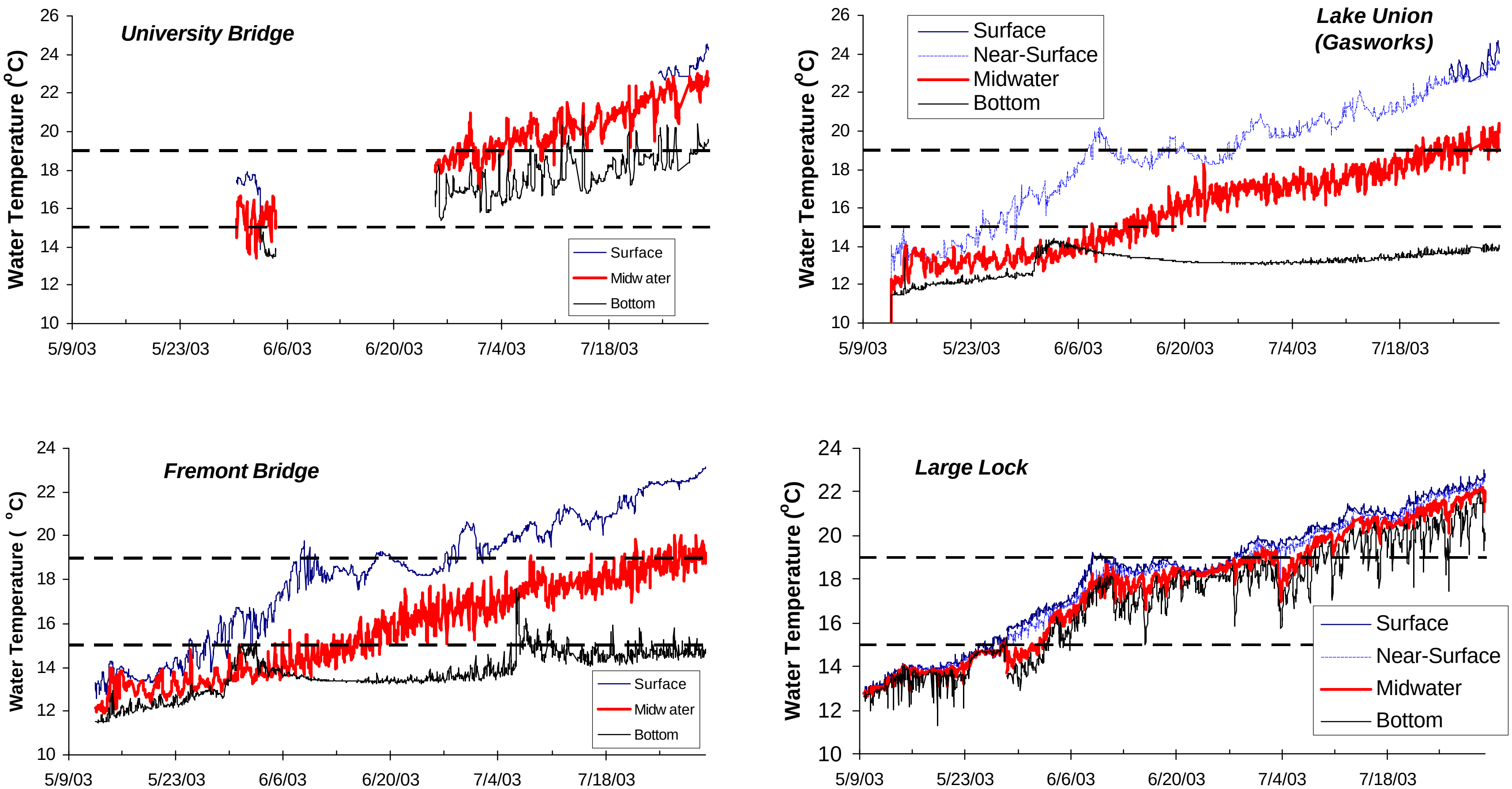


Figure 4-3. Temporal variation in water temperatures measured in the LWSC during the 2003 Lake Washington PIT tag study. The horizontal lines indicate approximate threshold criteria for optional growth (15°C) and avoidance and feeding inhibition (19°C).

preference has been correlated with optimal growth temperature, and the general preference of juvenile salmonids appears to be for temperatures that are about 15ºC and lower (McCullough 1999). By comparison, detection rates of tagged Bear Creek and Cedar River Chinook salmon began dropping for groups released around mid-May, 2003 (Figures 3-24 and 3-25). By the time roughly 50 percent of those fish had reached the LWSC, surface temperatures had reached 15ºC (Figure 4-3). Detection rates approached zero for groups released around mid-June, 2003. By the time roughly 50 percent of those fish had reached the entrance of the LWSC, surface temperatures had reached 19-20ºC. In 2001, 2002, and 2003, total daily detection rates and numbers began to drop off as surface water temperatures in the LWSC exceeded 15ºC and leveled off at very low numbers when the near surface mean daily temperature exceeded approximately 19-20ºC (Figure 4-4). This generally occurred around the beginning of July (Figure 4-5). Diurnal variation in LWSC surface temperature is generally less than 0.5ºC, so similar results are seen for daily minimum and maximum temperatures.

These results suggest that use of the smolt flumes may have little benefit for smolt passage as some upper temperature threshold is approached in surface waters of the LWSC, and could be closed until the next spring for purposes of saving water for the saltwater drain, lockages, and the fish ladder instead. What level that threshold temperature should be remains to be determined, and will likely balance water availability, water use, water quality, and fish passage objectives. The highest mean daily temperature in 2003 with flume passage (1 tagged Chinook smolt) was 20.5 C before the flumes were shut down for the season. Previous years showed flume passage, albeit in small numbers (0-9 fish/day), at mean daily surface water temperatures as high as 22 C (Figure 4-4).

4.2.3 "Best" Survival Estimates

The decreasing detection rates observed in Figures 4-1 and 4-2 indicated that survival could not be estimated for all fish combined over all release groups from a given location, since the proportion using the flumes (P_{SF}) was not constant over the course of the outmigration season. Similarly, survival could not be determined for release groups released the same week because the value of P_{SF} could not be estimated to high precision for all weeks monitored. However, calculating release and detection numbers on a weekly basis and assuming similar detection probabilities for each subgroup arriving the same week at the Locks, facilitated canceling out the proportion using the flumes (after factoring in migration rate) when estimating route segment survivals. This appeared to be a reasonable compromise because the detection rates of daily release groups were statistically similar within a weekly time interval (based on variance of a proportion).

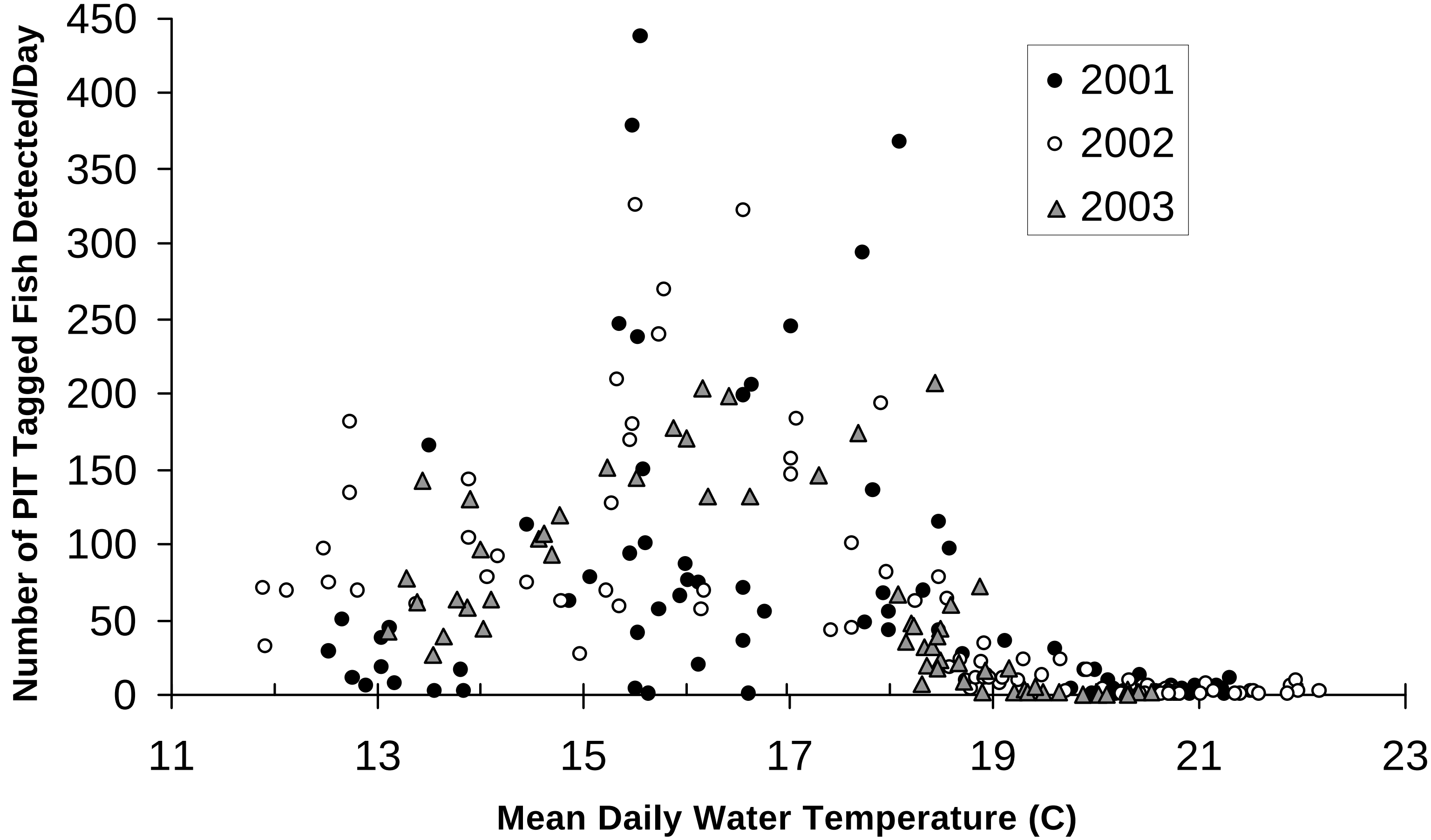


Figure 4-4. Variation in daily detection numbers in the smolt flumes with mean daily surface water temperature in the LWSC 2001, 2002, and 2003.

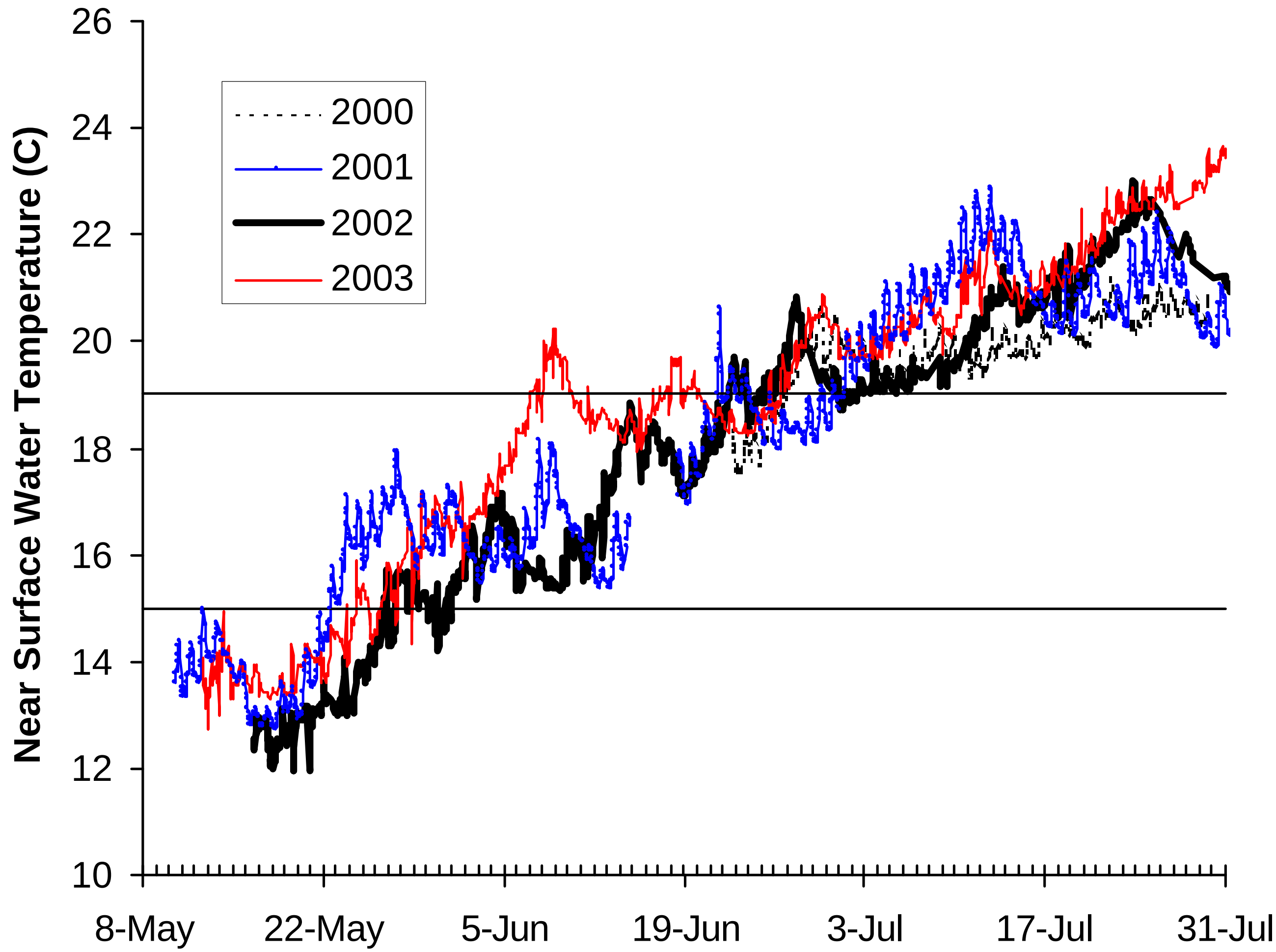


Figure 4-5. Between-year variation in near-surface water temperatures in Lake Union near Gasworks Park, 2000-2003 (USACE data).

Table 4-2 summarizes the corresponding results of the 2001 and 2002 studies, which were associated with the most comprehensive and least suspect segment survival estimates (smolts were tagged and released periodically over the outmigration season at a number of locations in the LWSC in 2001, and water temperatures and flows were most conducive for estimating survivals in 2002). Variance calculations indicated that confidence levels of segment survival estimates increased more rapidly as release group numbers fell below about 200-300 fish. Detection rates for the Montlake Cut fish were generally greater than or equal to rates for the Fremont Cut fish, and survival estimates for tributary fish were similar to both locations, suggesting that survival in the LWSC is high, possibly as much as 100% during May and early June. Survival appears to decline in mid- to late June depending on the year. However, it could not be discerned using the available data whether the declines reflected actual mortality, an increasing tendency to residualize, or other factors. Some of the differences could be explained simply as sampling error associated with smaller sample sizes of some groups. One possible explanation is that predation mortality in the LWSC becomes significant only when water temperatures approach 20 C (Tabor et al., 2004). This factor would be expected to affect survival of later migrating Chinook and sockeye young of year smolts the most, and earlier migrating, yearling (and older) smolts the least.

4.3 INFLUENCE OF LOCK OPERATIONS ON PASSAGE AND ESTUARINE TRANSITION

The 2003 PIT tag data further corroborate findings from previous years that suggest there are several features of lock construction or operation that may influence downstream passage and the transition to saltwater. These include seasonal and diurnal environmental and operational features that may result in changes in passage behavior, and are evaluated below.

4.3.1 Influence on Juveniles Located Above the Locks

4.3.1.1 Influence of Lock Fillings

A behavioral influence of lock operations is suggested by the PIT tag data regarding the movement of juveniles located above the Locks and subsequent passage. Each year there was a strong diurnal timing of passage at the Locks, with the majority (>90%) of passage occurring during daylight on dates that the flumes were open 24 hours (e.g., Figures 3-19 and 3-20). A similar trend was noted during regular spill through another gate in 2000 (BioSonics, Inc. 2001). This trend was used as a basis for revising operations in 2002, 2003, and currently in 2004 to conserve water. Sockeye salmon appeared to exhibit the strongest behavior, with no fish passing during nighttime hours in 2000. Peak passage numbers occurred overall during mid-morning

Table 4-2. Estimated survivals over different segments of the salmon juvenile outmigration route in the Lake Washington system, 2001-2002.

			Release Groups, By Week of Release					**Estimated Migration Route Segment "Survival" (+/- 95.1 C.I.)[1]**					
Species	**Year**		**Issaquah Hatchery**	**Bear Creek**	**Cedar River**	**Montlake Cut**	**Fremont Cut**	**Issaquah Hatchery - Bear Creek**	**Bear Creek - Montlake Cut**	**Bear Creek - Fremont Cut**	**Cedar River - Montlake Cut**	**Cedar River - Fremont Cut**	**Montlake - Fremont Cut**
Chinook	2001	Week of Release	--	5/14/01	5/21/01	5/28/01	6/4/01	--	53% (17%)	57% (36%)	*na*	*na*	*na*
		No. Released	--	357	142	110	23						
		No. in Flumes [2]	--	71	63	41	8						
		Week of Release	5/14/01	5/21/01	5/28/01	6/4/01	6/11/01	*na*	54% (14%)	60% (17%)	81% (17%)	90% (22%)	*na*
		No. Released	4676	320	374	236	160						
		No. in Flumes	1762	74	131	102	62						
		Week of Release	--	5/28/01	6/4/01	6/11/01	6/18/01	--	34% (9%)	44% (11%)	67% (17%)	87% (20%)	*na*
		No. Released	--	685	320	255	551						
		No. in Flumes	--	89	82	98	162						
		Week of Release	--	6/4/01	6/11/01	6/18/01	6/25/01	--	27% (29%)	14% (8%)	94% (90%)	50% (13%)	53% (50%)
		No. Released	--	277	360	23	516						
		No. in Flumes	--	13	59	4	170						
	2002	Week of Release	5/28/02	5/28/02	5/28/02	5/28/02	6/4/02	95% (11%)	84% (14%)	100% (17%)	87% (24%)	*na*	*na*
		No. Released	4024	463	84	300	370						
		No. in Flumes	1570	191	36	147	153						
Coho	2001	Week of Release	--	4/30/01	4/30/01	5/21/01	5/21/01	--	--	83% (71%)	--	67% (57%)	--
		No. Released	--	60	110	0	5						
		No. in Flumes	--	30	44	0	3						
		Week of Release	--	5/7/01	5/7/01	5/28/01	5/28/01	--	--	73% (25%)	--	72% (24%)	--
		No. Released	--	274	268	0	21						
		No. in Flumes	--	134	128	0	14						

Table 4-2. Estimated survivals over different segments of the salmon juvenile outmigration route in the Lake Washington system, 2001-2002.

			Release Groups, By Week of Release					Estimated Migration Route Segment "Survival" (+/- 95.1 C.I.)[1]					
Species	**Year**		**Issaquah Hatchery**	**Bear Creek**	**Cedar River**	**Montlake Cut**	**Fremont Cut**	**Issaquah Hatchery - Bear Creek**	**Bear Creek - Montlake Cut**	**Bear Creek - Fremont Cut**	**Cedar River - Montlake Cut**	**Cedar River - Fremont Cut**	**Montlake - Fremont Cut**
		Week of Release	--	5/14/01	5/14/01	6/4/01	6/4/01	--	*na*	*na*	*na*	*na*	89% (81%)
		No. Released	--	376	486	11	44						
		No. in Flumes	--	172	240	4	18						
		Week of Release	--	5/21/01	5/21/01	6/11/01	6/11/01	--	*na*	75% (17%)	*na*	85% (19%)	46% (38%)
		No. Released	--	297	323	19	90						
		No. in Flumes	--	127	156	5	51						
		Week of Release	--	5/28/01	5/28/01	6/18/01	6/18/01	--	--	--	--	*na*	--
		No. Released	--	2	43	0	41						
		No. in Flumes	--	0	20	0	16						
Sockeye	2001	Week of Release	--	--	--	5/7/01	5/7/01	--	--	--	--	--	100% (67%)
		No. Released	--	--	--	4	435						
		No. in Flumes	--	--	--	3	325						
		Week of Release	--	--	--	5/28/01	5/28/01	--	--	--	--	--	59% (42%)
		No. Released	--	--	--	12	402						
		No. in Flumes	--	--	--	5	285						
		Week of Release	--	--	--	6/4/01	6/4/01	--	--	--	--	--	*na*
		No. Released	--	--	--	11	23						
		No. in Flumes	--	--	--	1	1						
		Week of Release	--	--	--	6/11/01	6/11/01	--	--	--	--	--	91% (46%)
		No. Released	--	--	--	66	72						
		No. in Flumes	--	--	--	20	24						

Table 4-2. Estimated survivals over different segments of the salmon juvenile outmigration route in the Lake Washington system, 2001-2002.

			Release Groups, By Week of Release					Estimated Migration Route Segment "Survival" (+/- 95.1 C.I.)[1]					
Species	**Year**		**Issaquah Hatchery**	**Bear Creek**	**Cedar River**	**Montlake Cut**	**Fremont Cut**	**Issaquah Hatchery - Bear Creek**	**Bear Creek - Montlake Cut**	**Bear Creek - Fremont Cut**	**Cedar River - Montlake Cut**	**Cedar River - Fremont Cut**	**Montlake - Fremont Cut**
		Week of Release	--	--	--	6/18/01	6/18/01	--	--	--	--	--	70% (32%)
		No. Released	--	--	--	33	384						
		No. in Flumes	--	--	--	13	215						
		Week of Release	--	--	--	6/25/01	6/25/01	--	--	--	--	--	8% (11%)
		No. Released	--	--	--	38	519						
		No. in Flumes	--	--	--	2	359						

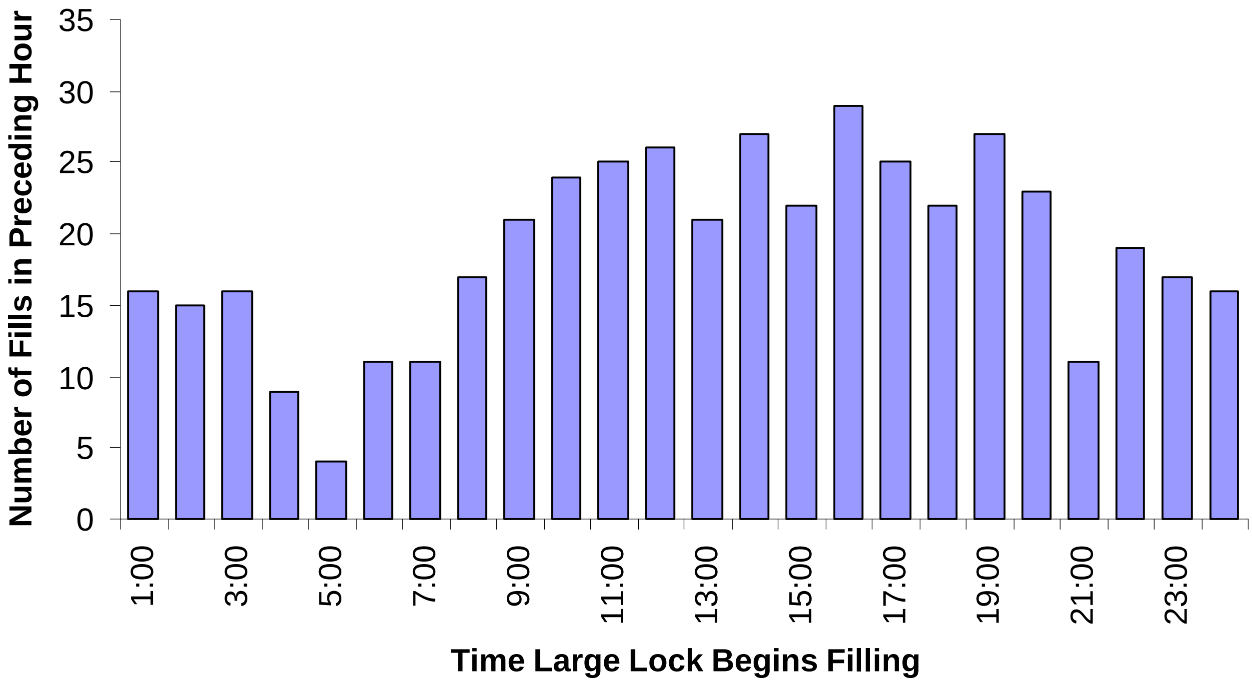
[1] *- na = estimate not possible because downstream group detection rate < upstream group detection rate; survival may be » 100% assuming no unexplained variation such as post-handling mortality.*
[2] *- Corrected for Detection Efficiency*

hours. In general, hourly passage timing distributions were not significantly different between stocks for a given species in any given year (á=0.05), suggesting that passage behavior was influenced more by conditions at the Locks than at the various tagging locations. A plausible mechanism may be that lock filling operations influence passage timing in the flumes through transient changes in velocity patterns occurring in the forebay area. Responses by smolts to temporal and spatial changes in velocity have been noted elsewhere (e.g., in the Stanislaus River by Cramer and Demko 1993; in the Columbia River by Johnson et al. 2000). Juveniles may be induced to swim more actively in the forebay area in response to unsteady flows when local currents increase temporarily while the large or small locks are filling (Figure 3-23). Increased swimming activity may increase the probability that outmigrants encounter the smolt flume entrances, with increased probability of passage. In corroboration, passage rates during fills of either lock were roughly twice passage rates between successive fills in all years; the difference was significant at the 95% confidence level in each case. The proximity of the small lock to the flumes and greater frequency of fillings overall compared with the large lock, and the greater similarity in the shapes of the frequency distributions of hourly passage timing and lock fillings with respect to daytime:nighttime differences (cf. Figures 3-19 and 4-6), suggest that strongest passage response exists with respect to small lock fillings than with large lock fillings. The greater proportion of passage during the morning hours compared with the afternoon could reflect fish that arrive overnight and are waiting for passage cues provided by the small lock.

4.3.1.2 Influence of Flume Flow Rate

The benefits of flume flow rate depend in part on how detection numbers are used to define flume effectiveness or efficiency. There are two ways these terms may be defined: total number of fish passed per day (it is proposed here that this be termed “effectiveness”), and total number of fish passed per unit volume of water per day (proposed here as “efficiency”). The distinction is important in the context of water management and fish passage. For example, in 2003, Flume 5C passed a similar or greater number of Chinook and coho salmon smolts per m^3 per day than Flume 5B when both were open (Figure 4-7). However, Flume 5B passed a similar or greater absolute number of fish each day than 5C (Figure 4-8). When only 5C and 4B were open, however, the larger flume (4B) passed greater fish numbers each day. Both metrics appear to depend on the number and configuration of flumes in operation.

Daily and weekly variations in detection numbers have been relatively large during each year PIT tags were used, and flume operations have also been variable in terms of the number and which flumes are open on a given day and time. It has therefore not been possible to make definitive conclusions regarding the influence of flume size or flow rate on passage rates using



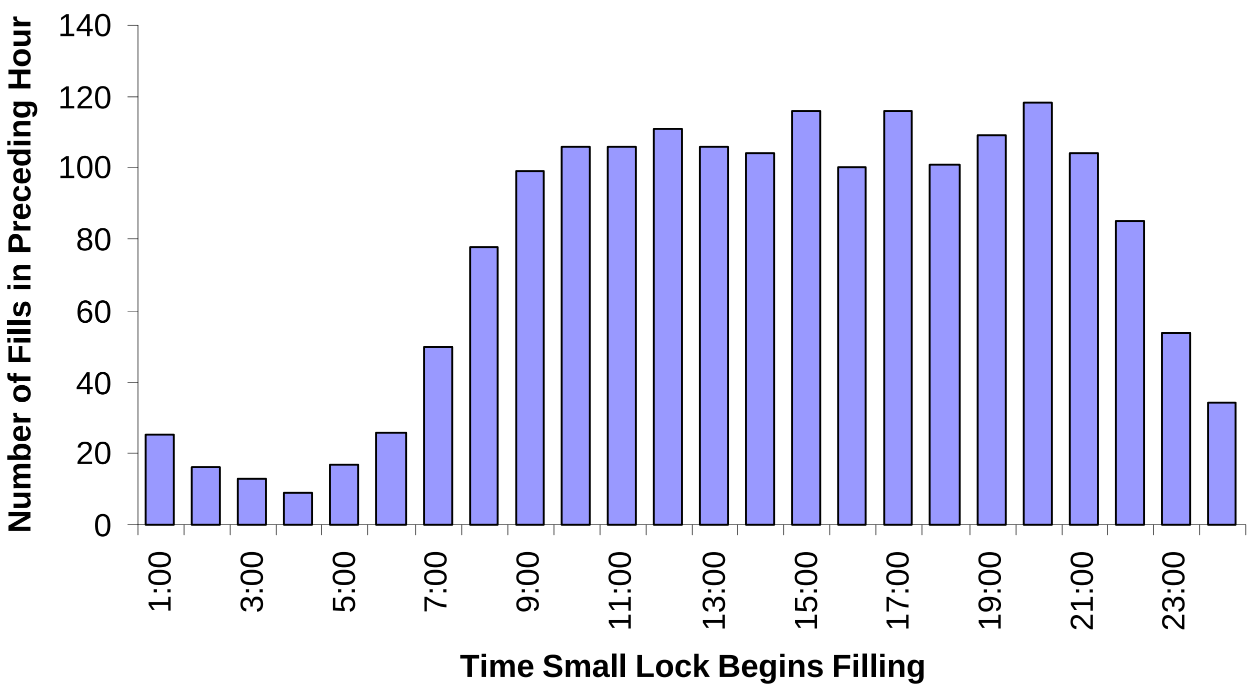


Figure 4-6. Diurnal variation in times at which the large and small locks began to fill during the 2003 Lake Washington PIT tag study period ending July 9, 2003.

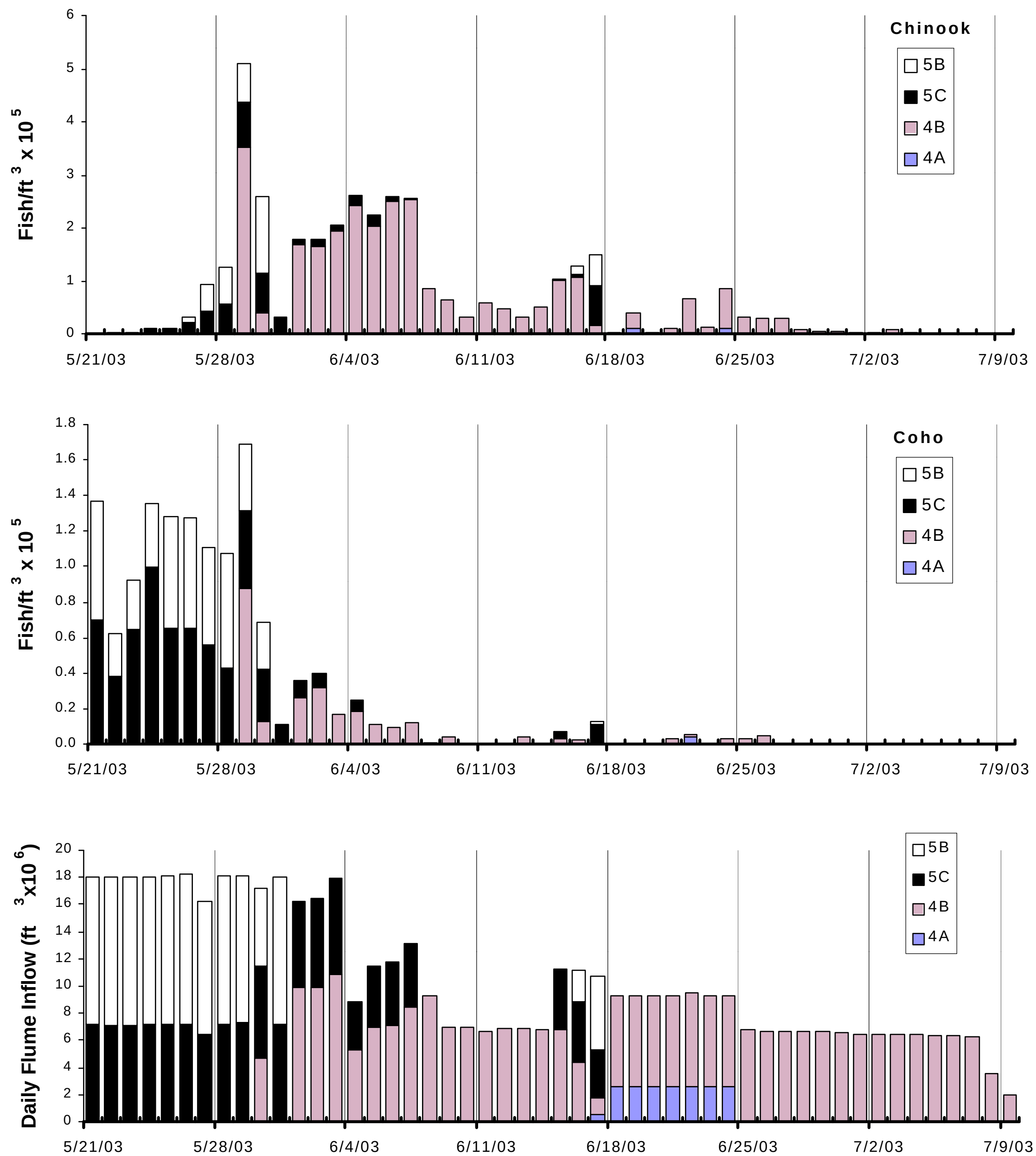


Figure 4-7. Number of all PIT tagged Chinook and coho salmon passing through each flume normalized to unit discharge, and corresponding flume volumes during the 2003 Lake Washington PIT tag study.

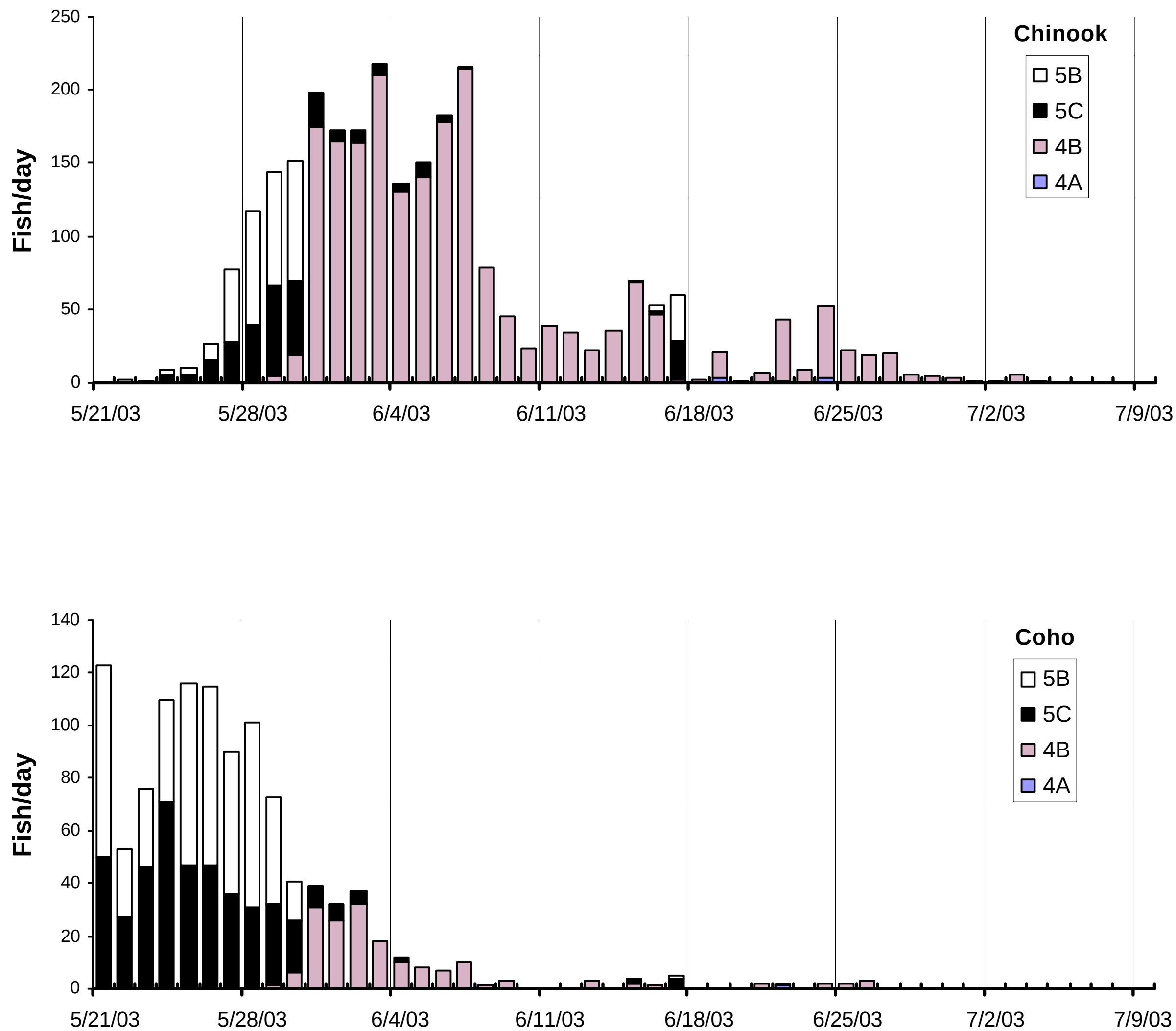


Figure 4-8. Total daily number of all PIT tagged Chinook and coho salmon passing through each flume during the 2003 Lake Washington PIT tag study.

the PIT tag data from any one year, including 2003 when flume operations were most curtailed out of the four years of study. Some hypotheses are suggested, however, when the data are reviewed collectively over the 2001-2003 period (2000 releases were over a shorter duration and thus could not be used to evaluate flume effectiveness or efficiency).

The collective results suggest that the total flow entering a gate may be an important influence on juvenile behavior in the forebay vicinity and subsequent passage through the smolt flumes, as opposed to simply flow rate summed over both gates when only two or three flumes are open. This suggestion makes some intuitive sense in that the velocity fields in the two spill gates appear visually to be relatively independent of one another. Data from other studies have suggested that passage rates through Gate 2 increase with spill flow rate (BioSonics, Inc. 2001). Results from the 2001 and 2002 PIT tag studies have similarly suggested that, overall, the greater the total flow, the more tagged fish are detected in the flumes. The 2002 results were particularly useful in that it was a wetter, cooler spring and all four flumes were open for longer in the outmigration season than in other years. The numbers of PIT tagged Chinook passing through Gate 5 in 2002 were larger per unit volume of water than in Gate 4 when all four flumes were operational. Since Gate 5 passes 55% of the total flow, this suggests that gate attraction flow is important when all four flumes are open. In addition, Pfeifer (2003) evaluated effects of different combinations of flumes on the ratio of estimated flume passage to culvert entrainment numbers during the Chinook smolt outmigration period. Flumes were open from 0600 to 1800 hours each day during the tests. The 2002 PIT tag data correspondingly suggest a positive relationship existed between total flume flow rate and number of PIT tagged Chinook salmon smolts detected from Bear Creek, the Cedar River, and Issaquah Hatchery (Figure 4-9; after factoring out the effect of water temperature and run timing by considering only detection data between the initiation of the main part of the run of each stock and June 29, 2002 when surface temperatures regularly exceeded 19 C in the LWSC). A trend was less clear for flow efficiency using the same data (Figure 4-10). Only Cedar River Chinook detections per cfs showed a significant positive regression relationship with nominal flume flow rate (p=0.014), where flow efficiency increased until both large flumes and the small flume are open. Relationships for Bear Creek and Issaquah Hatchery Chinook were essentially flat, however, suggesting that greatest marginal benefits of increasing flume flow occur below 130 cfs when looking at the three stocks overall (but there are no data points in Figures 4-9 and 4-10 for Flumes 5C or 4A alone to confirm this).

There was no clear preference for a specific flume. The large flume 5B passed more fish per unit volume of water in 2002 than flume 4B, whereas 4B passed more in 2001 (Figure 4-11; similar

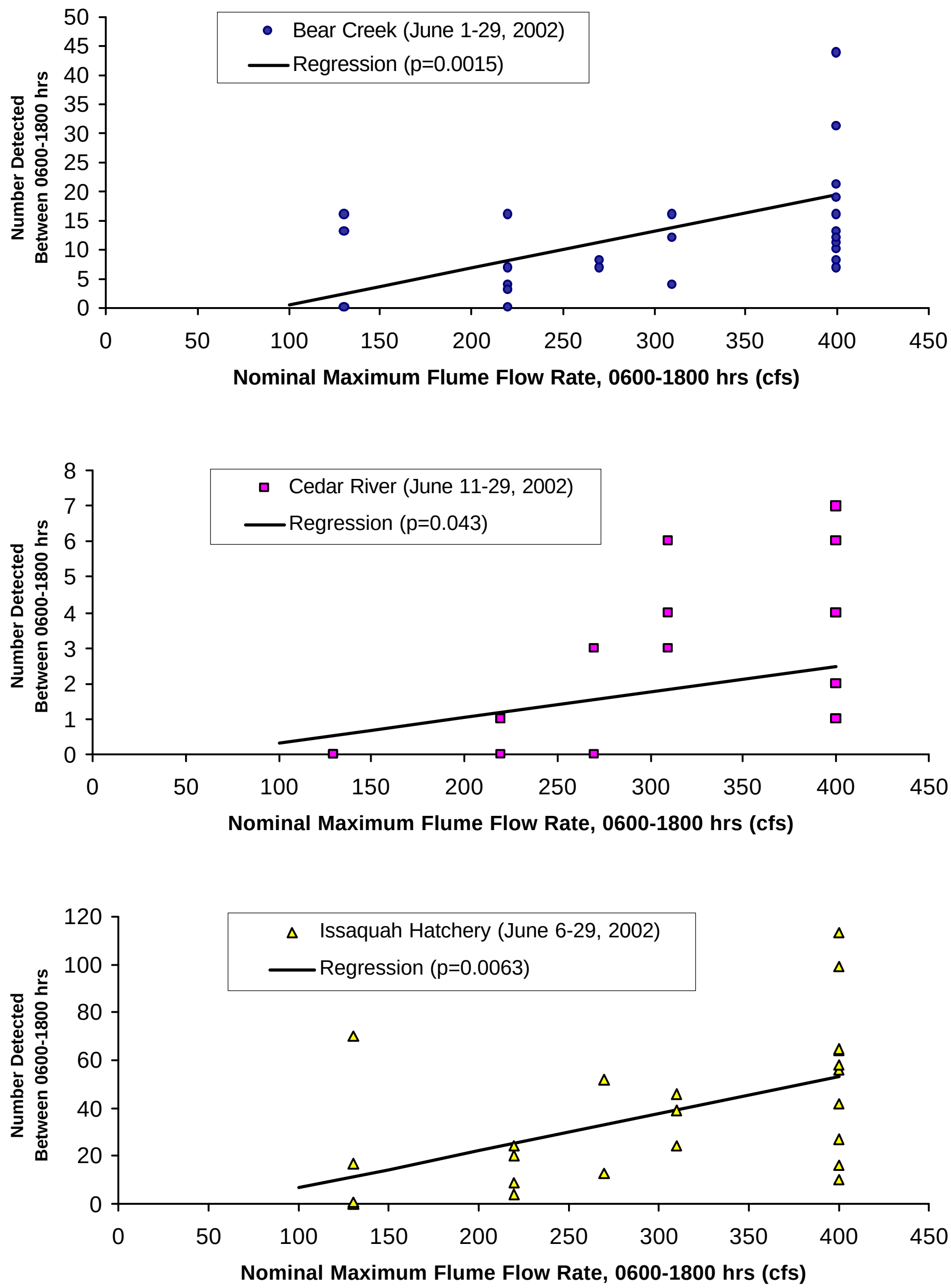


Figure 4-9. Relation between flume flow rate and PIT tag detection numbers ("flow effectiveness") for Chinook salmon smolts from Bear Creek, the Cedar River, and Issaquah Hatchery in 2002 during the main portion of the run, and before elevated water temperatures began to have a strong influence on passage rates.

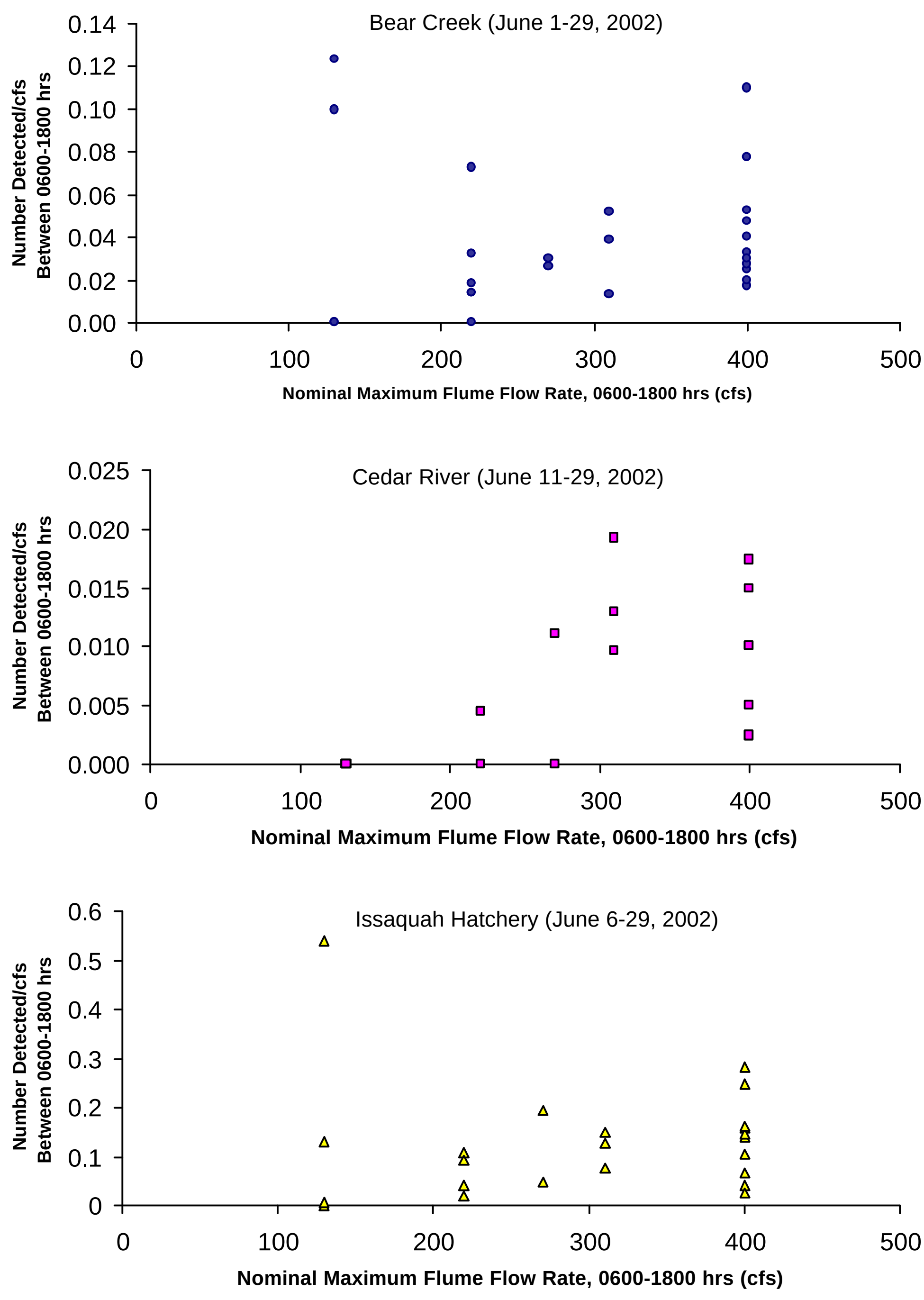


Figure 4-10. Relation between flume flow rate and PIT tag detection numbers per unit volume of water ("flow efficiency") for Chinook salmon smolts from Bear Creek, the Cedar River, and Issaquah Hatchery in 2002 during the main portion of the run, and before elevated water temperatures began to have a strong influence on passage rates.

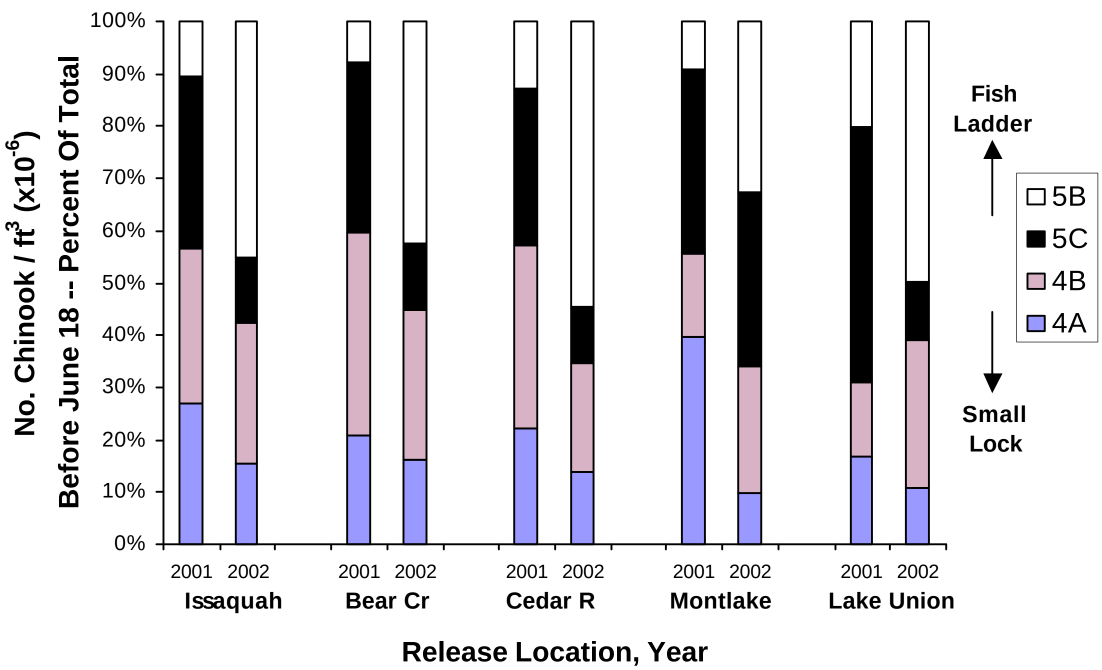


Figure 4-11. Chinook juvenile passage rates per unit volume of water flowing in each flume (4A, 4B, 5C, 5B) in 2001 and 2002, while all four flumes were open the same time. After June 18, selected flumes were shut down to conserve water.

comparisons could not be made for 2000 and 2003; see Figure 3-1). The intermediate sized flume 5C passed more fish per unit volume of water than the larger flume 5B in 2001, and fewer in 2002. Passage rates were generally greater in a gate when both flumes were operational than when only one flume was open. However, the 2002 study data also indicated a degree of compensation may exist for the medium and large flumes (4B, 5B, 5C), where the number of fish per cfs per day can increase in a flume when it is the only one open in a gate compared with both flumes being open (DeVries 2003). Gate 4 was closed during the day on June 1 and 2, 2002. During that time, proportionally more coho used Gate 5 than on preceding and succeeding days, while the total numbers detected remained about the same. A similar pattern occurred for both Chinook and coho salmon smolts on June 24-26, 2002. On June 8 and 9, 2002, the two larger flumes 4B and 5B were closed during the day. On this occasion, proportionally more tagged Chinook and coho used the intermediate sized flume (5C) than on preceding and succeeding days, yet the total numbers detected again remained about the same. In contrast, use of the smallest flume (4A) did not change appreciably. These results suggest that when one gate (or the large flume in a gate) is closed, outmigrating smolts seek alternate routes and the passage rates in the remaining open flumes can increase correspondingly.

If generalizations can be made, they appear to be that:

1. The small flume (4A) passes relatively few fish, especially when it is the only one open in Gate 4. Flume 4A does not appear to pass enough water by itself to attract additional smolts when flume 4B is closed. For example, this phenomenon was noted clearly in the 2001 study for hatchery Chinook released from the University of Washington, and was also seen in Pfeifer's (2003) 2002 results.
2. The medium size flume (5C) may exhibit a similar or higher flow efficiency than the large flume (5B) when just those two flumes are open, but the large flume typically has a higher flow effectiveness; this phenomenon was observed in 2001 and again in 2003 (Figures 4-9 and 4-10). When all four flumes are open, each of the large flumes exhibits both higher flow effectiveness and efficiency than the smaller flume in their respective gates; this phenomenon was observed in 2001 and 2002.

In summary, passage numbers of PIT tagged fish appear to increase with number of flumes open, although the strength of this relation is likely influenced by the compensation effect noted above and the daily and seasonal variability seen in passage numbers.

4.3.2 Influence of Locks on Juveniles Located Below the Locks

As in previous years, the tunnel detector data from 2003 indicate that some Chinook and coho salmon smolts recycled through the Locks (Figure 3-22). It is unknown whether this was because (i) fish were entrained during lock openings and became disoriented, (ii) some fish that passed through the flumes were not completely smolt-ready and thus actively avoided more saline water by swimming upstream through the Locks in the less saline lens, or (iii) fish were swimming about in pseudo-random movements that were directed on average in the upstream direction. The phenomenon has been most prevalent for the calibration test fish, but some natural origin Chinook and coho have also been observed to recycle more than twice in both 2002 and 2003 (DeVries 2003; Figure 3-22). Sockeye salmon juveniles were never observed to recycle. The lower recycling rate observed in 2003 than in 2002 or 2001 may reflect the influence of water temperature on passage behavior.

The influence of entrainment into the large lock is difficult to evaluate because of the physics involved in density currents. As the lower gate is opened, a saline wedge intrudes near the bottom into the large lock chamber, resulting in downstream displacement of a surface lens of the relatively well-mixed, but less saline water initially present in the lock chamber (Lingel 1997). If juvenile salmonids are to be entrained physically from downstream, they would have to be present primarily within the deeper, more saline water that moves upstream. Fish present nearer the surface would tend to be moved in the downstream direction because of the density currents (Lingel 1997). Alternatively, if juveniles were seeking fresher water, they would initially have to swim upstream against the surface discharge of less saline water. Once inside the chamber, the same process is repeated when the upper gate is opened. Hence, if fish are indeed entrained in the upstream direction to above the locks, they would have to be consistently within the deeper parts of the water column. Underwater video data and visual observations suggest that salmonid smolts are surface oriented in the vicinity of the locks structures, while acoustic data show that surface-oriented aggregations, when entrained through filling culverts into the large lock chamber, resume their surface orientation within minutes (J. Dawson, Biosonics Inc., personal communication). Research in the Columbia River estuary indicates a large fraction of smolts in the estuarine transition zone, including particularly those of hatchery origin, may be found in the low salinity, upper portions of the water column where they are vulnerable to avian predation (Collis et al. 2001). The extent of association with the low salinity lens appears to increase with stress (Seals Price and Schreck 2003). In addition, Johnson et al. (2001) determined that fish near the entrance to the large lock filling culvert entrance were distributed in two distinct groups, one near the bottom and one near the surface. Although species in each group were not determined, the composition may reflect vertical salinity differences with downstream migrant smolts remaining in the upper freshwater layer when the upper gates are opened, and shiner surfperch (*Cymatogaster aggregata*) residing in the lower layer. A tendency to spend time in the surface layer below the Locks would reduce the likelihood of physical entrainment in the upstream direction during gate opening operations.

Smolts that may be entrained upstream in the saltwater wedge and re-exposed to lake water may be able to similarly withstand the transition (particularly chum and coho salmon; Clarke and Hirano 1995), but the physiological costs and resulting stress levels have not been determined in the case of the Locks and elevated water temperatures in the LWSC. This would need to be addressed, for example, if it were determined that saltwater-acclimated smolts were entrained upstream in the deeper, cooler, more saline layer.

Another potential effect of elevated water temperatures in the LWSC that could influence both numbers reaching the estuary and successful transition to saltwater may be premature smolting and desmoltification, which has been observed for Chinook and coho juveniles (Wedemeyer et al., 1980). It is unknown if this is a factor contributing to smaller numbers of these species than sockeye salmon in the basin overall; this appears worthy of further investigation.

Water quality profile data collected below the Locks by C. Simenstad and W. Couch of the University of Washington in 1999, and by D. Houck of King County/Metro in 2000 and 2001 indicate that there is a low-salinity lens in roughly the upper 1 to 3 meters of the water surface that is less than 20 ppt in concentration. This lens sometimes extends out to the railroad bridge and beyond depending on discharge at the Locks and tide. Data collected in 2001 suggested that a rapid osmotic transition had occurred in many of the juveniles captured in the beach seine samples in the inner bay area, where salinities nearer the surface were on the order of 15-20 ppt during the spring outflow months. A Chinook smolt from Bear Creek was recaptured within 7 minutes of having passed through the flumes, and a coho smolt from the Cedar River was recaptured within 40 minutes. Juvenile and fry Chinook salmon are capable of sudden transitions from freshwater to water with salinities as high as 16 to 20 ppt without apparent adverse survival effects (Macdonald et al. 1988; Healey 1991; Clarke and Hirano 1995; Kreeger 1995). However, tolerance of even 30 ppt has been noted to not be an adequate criterion for identifying smolts (Clarke and Hirano 1995), and thus it is possible that the relatively quick transition may still be stressful (Macdonald et al. 1988). The possibility also exists for increased delayed mortality in saltwater after the transition, associated with scale loss when water temperatures in the LWSC increase to stressful levels during the outmigration season (Clarke and Shelbourne 1985). Blood chemistry sampling of PIT tagged fish passing through the flumes and caught downstream would provide more direct evidence of physiological stress and smolt readiness. In any case, the PIT tag data suggest that the downstream migrants spend relatively little time in the lower salinity lens below the locks before making the transition to higher salinity water. They thus appear to spend relatively little time in an 'estuarine' setting with salinities below 10 ppt.

PIT tagged hatchery Chinook smolts tended to remain in the inner bay for longer than PIT tagged natural origin Chinook, coho, and sockeye smolts, based on tag recovery data (Figure 4-12). PIT tagged sockeye salmon smolts were never caught below the Locks, and together with the absence of recycling behavior, are assumed to head quickly into Puget Sound after passing the Locks. The result may reflect the availability of an abundant food source below the locks. Lake Washington and the LWSC contain large populations of cladocerans and other freshwater zooplankton during the spring. Large densities of these organisms die as they are flushed from freshwater into the saline inner bay. Simenstad et al. (2003) determined in their sampling in the inner bay in 2001 that freshwater cladocerans contributed a greater fraction of an index of relative importance in the diet of hatchery Chinook than of natural origin Chinook. Since hatchery Chinook were raised eating large quantities of readily available food, it is plausible that they remain longer in the environs of the inner bay than natural origin fish because of a plentiful and readily available food supply. It is difficult to confirm this, however, because large numbers of hatchery and natural juvenile salmonids originating from other basins appear to move into the inner bay to feed on the abundant freshwater zooplankton as well (Simenstad et al. 2003). Nonetheless, the PIT tag results are consistent with seining data collected in a companion study below the locks (Simenstad et al. 2003), in which hatchery Chinook constituted a large fraction of catches within the inner bay, particularly before mid-June 2001, whereas natural origin Chinook, coho, and sockeye juveniles were caught more sporadically.

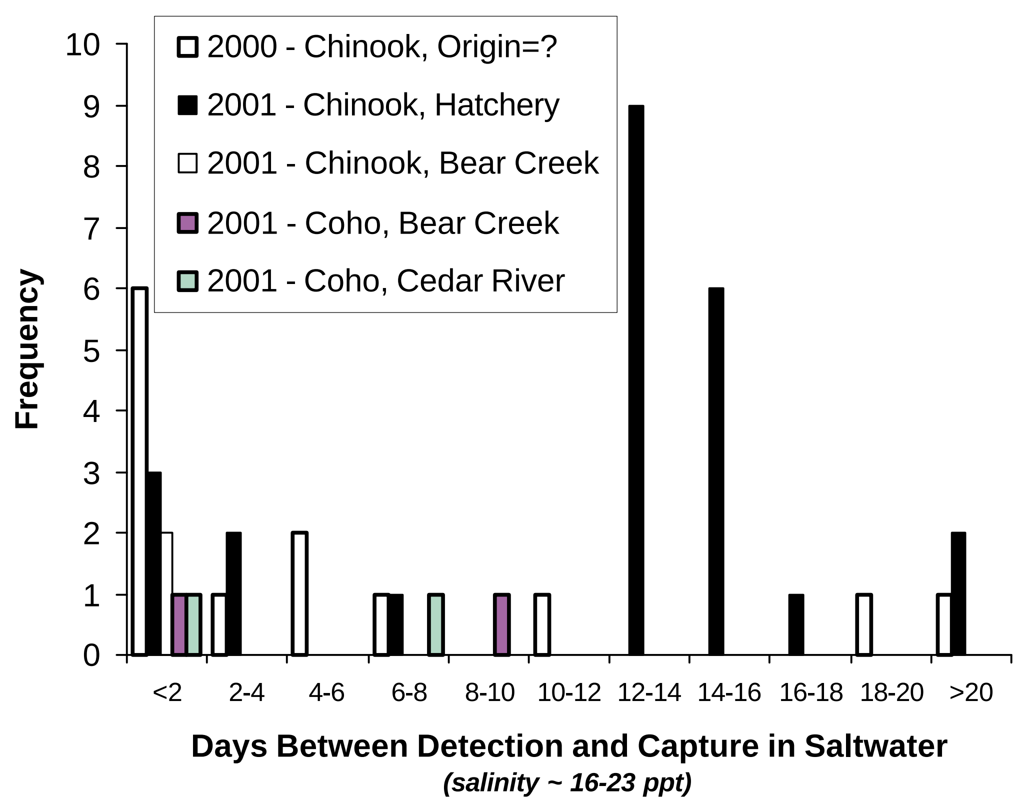


Figure 4-12. Times between passage through the flumes and recapture in saltwater below the Locks in 2000 and 2001, Lake Washington GI Study.

In summation, the PIT tag recapture data suggest that smolts may spend relatively little time in an "estuarine" setting, and that they undergo a rapid osmotic transition below the Locks. It is unknown if this is harmful, although the weight of the evidence suggests it may not be harmful for the environmental conditions specific to the Locks. More research is needed on this specific issue.

4.3.3 Suggested Changes in Operations

Only two changes to flume operations are suggested by the data presently. Because nearly all PIT tagged fish passed through during daylight hours in all three years, the flumes could be shut off at night to conserve water so that they can be open to passage for a longer period during the smolt migration season, possibly through the end of July. The PIT tag data suggest that more than 90% of the tagged fish passed through the flumes between daybreak and dusk in May and June. A similar trend was noted in spill gate #2 in 2000 (BioSonics, Inc. 2001). The reason for this is suspected to be related to the frequency that the small and large locks are filled. This phenomenon could be tested in subsequent years by specifying a daytime opening pattern on alternating nights (i.e., uniform lock opening distribution over 24 hours vs. normal operations) and comparing diurnal passage rate variation on successive dates. Since small and large lock fill times reflect use patterns that are unlikely to change, shutting the flumes down at night helps address water conservation needs for improving smolt passage at the Locks, a significant problem identified by USACE (1998).

The second change suggested by both the 2001 and 2002 data is that the flumes could potentially be shut down for the season when surface water temperatures in the LWSC in the vicinity of the Locks reach 19ºC, 20ºC, or 21ºC. The route of passage appears to shift to deeper alternatives, with few fish using the flumes after that temperature threshold is reached. Which temperature threshold is appropriate remains to be determined, for the reasons given in Section 4.2.2.

Other than possibly increasing attraction flows to the entrance of the smolt flumes (which could also increase the area of the freshwater-saltwater mixing zone in the spillway tailrace), no changes to lock operations are suggested by the PIT tag data at this time. However, because there appears to be an influence of lock filling operations on smolt passage through the flumes, a possible future investigation would involve assessing behavioral guidance systems that induce smolts to move in the direction of the flumes when the Locks are filling through their culvert intakes. A review of recent work on the Columbia River system could provide an indication of whether appropriate structural measures would be technically feasible and applicable. The review should at the same time determine and compare the proportions of fish entering the large and small locks when the gates are opened to the numbers passing through the smolt flumes to determine whether guidance measures in particular would be expected to improve flume passage numbers measurably and economically.

4.4 SYNOPSIS OF OTHER BEHAVIORAL CHARACTERISTICS

4.4.1 General Species Observations

The PIT tagging studies revealed outmigration characteristics that were similar across species, but also many traits that were more unique. In summary, all three species exhibited similar diurnal passage timing distributions, and passage initiation of the bulk of the run appeared to be linked with lunar phasing albeit to differing extents between species (see Section 4.4.4). Chinook and coho salmon juveniles exhibited similar recycling behavior at the Locks, although it was generally stronger for Chinook.

Sockeye salmon exhibited the most distinct behavioral differences. Compared with Chinook and coho, PIT tagged sockeye salmon smolts consistently passed through the LWSC and Locks the earliest during the smolt outmigration season, followed by coho and then Chinook salmon. This pattern was corroborated in beach seining catches below the Locks in 2000 and 2001 during companion studies (Footen 2000; Simenstad et al. 2003). Sockeye salmon juveniles generally migrated the fastest through the LWSC, followed by coho and Chinook (Figure 4-13). PIT tagged sockeye also passed through the flumes more consistently during daylight hours, did not recycle through the Locks, and were not recaptured in the inner bay in 2000 or 2001. In addition, the length frequency data reflected the presence of two age classes residing in Lake Washington and passing through the locks. Larger yearlings tended to pass first, followed by smaller 0+ fish. Overall, larger sockeye juveniles appeared to be most "determined" to enter saltwater of the three species, and a majority did so before water temperatures in the LWSC became less hospitable. Later migrating, younger sockeye appear to have the option available to spend an extra year in the system and spend the summer in cooler, deeper lake water. Depending on the extent of freshwater predation in deeper water, which is currently not well documented (Tabor et al., 2004), this behavior could be an adaptation that benefits this species in this environment.

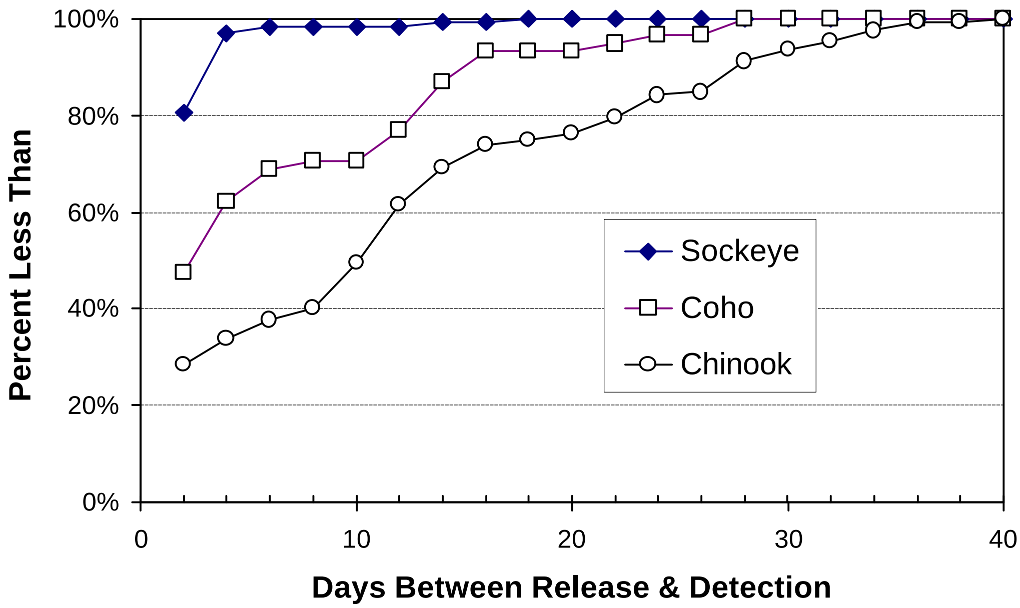


Figure 4-13. Travel time to the tunnel readers at the Locks, of sockeye, coho, and Chinook salmon smolts tagged and released near the entrance of the Fremont Cut in Lake Union, 2000 Lake Washington GI study.

4.4.2 Size-Dependent Influences

Total length of natural origin Chinook generally increased in the smolt trap catches as the migration season progressed (Figure 4-14). Lengths of coho smolts generally did not increase in the traps (e.g., Figures 3-11, 3-12). The limited number of recaptures of fish in freshwater indicated growth rates averaged 0.9 mm/day for Chinook (n=11; range: 0.5–1.5) and 1.2 mm/day for coho (n=4; range: 1.1–1.4) during the outmigration season of 2001. Growth rates were slower in 2003, averaging 0.5 mm/day for two Chinook and one coho (Table 3-4). However, it should be recognized that there was some variation in length measurements indicated by recapture data (Table 3-3). Temporal patterns in mean length also varied annually within a stock and between stocks. Mean lengths of Bear Creek Chinook typically leveled off or decreased in late May and early June before increasing again, potentially reflecting a set of distinct stocks within that sub-watershed. Conversely, mean lengths of Chinook in the Cedar River generally increased steadily over the outmigration season, reflecting a more homogeneous stock (Figure 4-14).

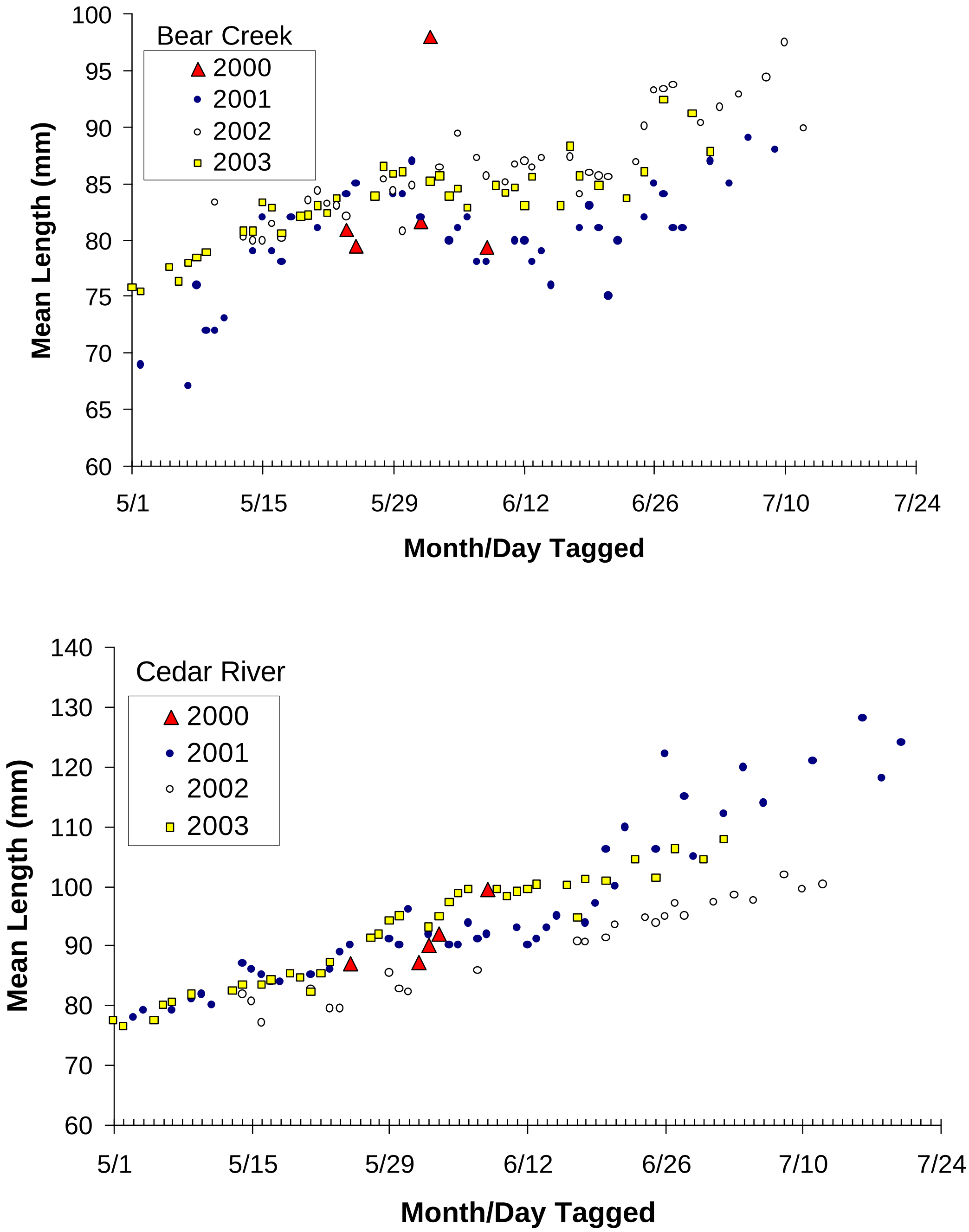


Figure 4-14. Temporal variation in mean lengths of Chinook caught, PIT tagged, and released in Bear Creek and the Cedar River, 2000-2003 Lake Washington GI studies.

There was no consistent bias evident in the 2000-2003 detection data that would suggest a significant size-dependent influence of PIT tagging on the study results overall. Cumulative length frequency distributions for all tagged fish in a stock were overall not significantly different from comparable distributions for member fish detected at the Locks. There was no significant difference in flume selection based on fish size in 2002 (Figure 4-15), and smaller fish were generally as likely to be detected at the Locks as larger fish most of the time. An exception occurred in some years, however, where larger Chinook smolts had a slightly greater detection rate than smaller fish for groups tagged and released after late May to early June (Section 3.3). The difference was not always statistically significant at the 95% confidence level, but the overall trend was consistent in 2001-2003 for Bear Creek Chinook smolts. The trend was not consistent for Cedar River Chinook smolts, and only occurred in 2003 although the difference in distributions was not significantly different (note erratum for 2001 report for Cedar River Chinook in Appendix C). A trend for larger fish to reach the locks more successfully than smaller fish could represent a subtle size-selective effect *en route*, through predation, residualization, or other factor.

Fish size also appeared to influence passage timing of sockeye and Chinook salmon, irrespective of the absence of tagging-induced bias, as indicated in the next section.

4.4.3 Residualism in Lake Washington

Nearly all fish tagged in a given year were detected at the Locks that same year, although a small number of Chinook, coho, and sockeye were detected passing through the Locks one to two years after tagging, and therefore must have residualized in the Lake Washington system. Coho salmon juveniles generally spend at least one year in the system, and thus the delayed detection of some, particularly smaller fish is not surprising. Both sockeye and Chinook salmon juveniles have been noted to residualize in the Lake Washington system to varying extents, where the multiple age class structure of the sockeye population has been well documented (e.g., Haw and Buckley 1962; Kolb 1971; Dykeman 1980; Jeanes and Hilgert 2002). Data collected as part of the PIT tag studies may provide additional insight regarding environmental factors influencing this phenomenon. Specifically, elevated water temperatures may explain the relative differences in the number of fish that stayed an extra year after tagging and passed in 2002 and 2003. Surface water temperatures were warmer earlier in the spring of 2001 and 2003 than in 2002. Correspondingly, a larger number of fish remained an extra year in the system and passed in 2002 than in 2003: of Chinook salmon tagged in 2001 and 2002 in Bear Creek, Cedar River, and the Issaquah Hatchery, 0.26% and 0.09% residualized, respectively based on comparing each year’s detection numbers; of coho salmon, 0.20% and 0.09% residualized, respectively.

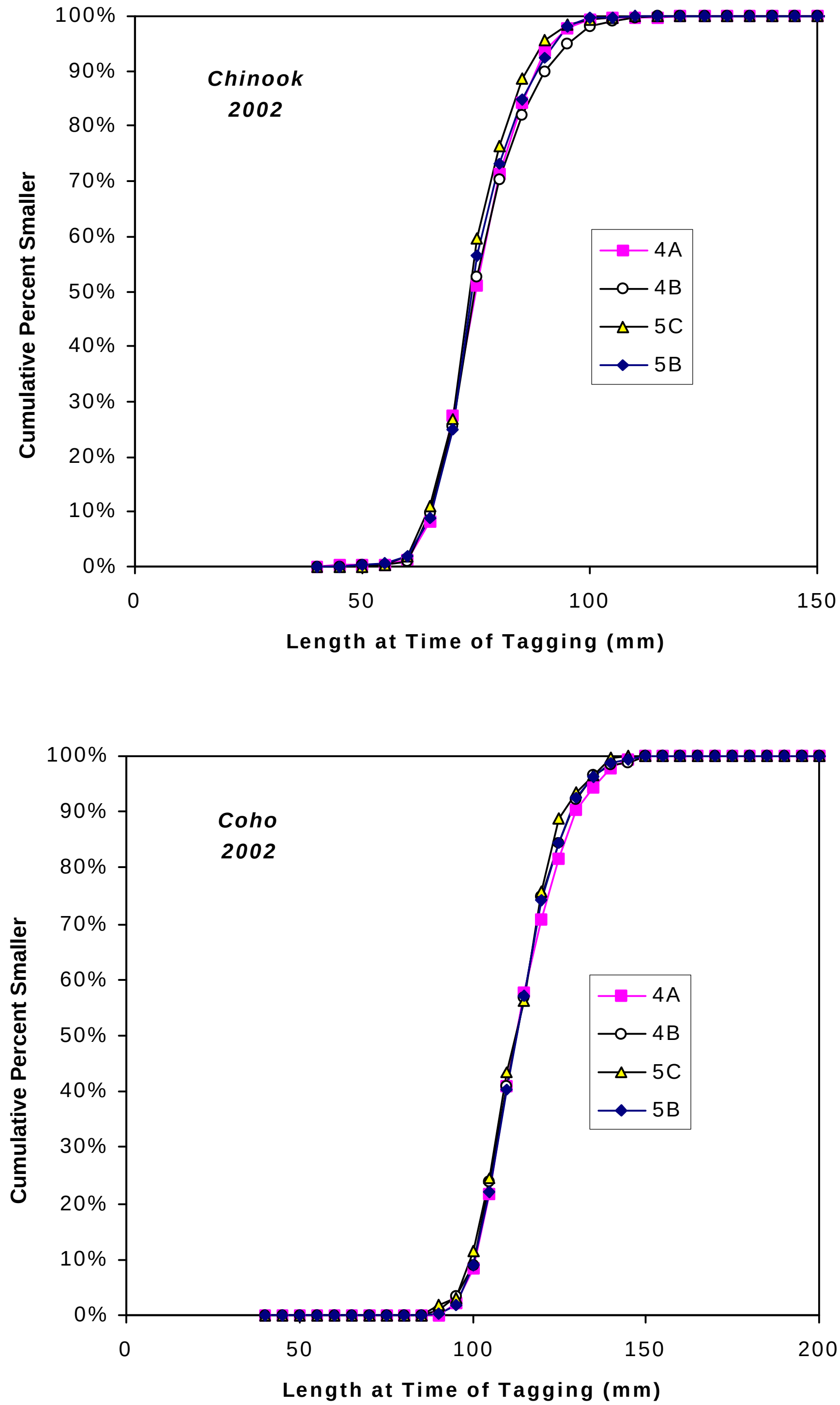


Figure 4-15. Comparison of PIT tagged Chinook and coho salmon smolt length frequency distributions between flumes during same period, 2002 Lake Washington GI Study.

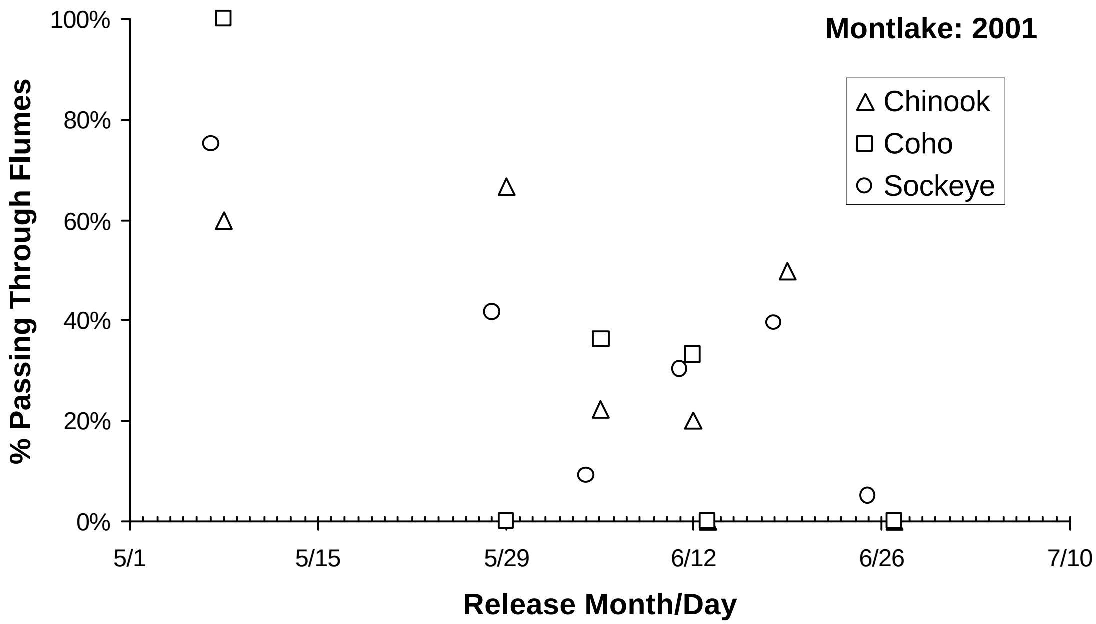
In addition, the earlier passage timing of sockeye salmon suggests that the stock as a whole may not be subjected as extensively to warmer water temperatures in the LWSC, although there was evidence that members of the later migrating 0+ age class may be induced to residualize for a year in the lake when temperatures increase in the LWSC. All of the sockeye that were detected at the Locks a year after tagging in Lake Union were from the smaller age class and were tagged during the latter half of June 2001 when temperatures began to regularly exceed 15°C (DeVries 2002). Brett (1952) determined that Chinook and coho were more tolerant of elevated temperatures than sockeye salmon juveniles, which may explain in part the earlier passage of larger sockeye and evidence of residualization of later migrating, younger sockeye.

Chinook that residualized for a year exhibited a size and timing trend similar to that of sockeye. One Chinook that remained an extra two years in the system entered Lake Sammamish in 2001 when surface water temperatures there regularly exceeded 15°C. The exit point of the lake draws water from the warmer epilimnion and is known to represent a thermal barrier in the Sammamish River downstream during late spring. The author captured Chinook salmon smolts as part of salvage efforts in North Creek, a cooler tributary, in August 2001 that were anal fin-clipped in the Sammamish River in early spring (Jeanes and Hilgert 2002). It is possible these fish entered North Creek temporarily, but then were discouraged from re-entering the Sammamish River as it warmed.

There is relatively little thermal stratification in late spring in the Fremont Cut, Montlake Cut, and Sammamish River, whereas bottom temperatures are cooler than surface temperatures in other locations in the LWSC and in lakes Washington and Sammamish. Hence, it is possible that the two constrictions posed by the LWSC and Sammamish River present thermal barriers to outmigrants in late spring and early summer. This may be corroborated by the data for Chinook, coho, and sockeye tagged and released in the LWSC in 2001: although detection rates were generally similar at each location, the decreasing temporal relationship for the Montlake fish was more consistent with that for the tributary fish, whereas the scatter was wider for fish tagged and released in Lake Union (Figure 4-16).

4.4.4 Lunar Phase and Passage Timing

A strong relation was apparent between lunar phase and the initiation of the main passage period for each species. Specifically, passage at the Locks became substantial within a few days of the date that the moon was at apogee (farthest from the earth); a weaker relationship was observed for the quarter moon phase (DeVries et al. 2004). The relationship was strongest for Chinook (Figure 4-17) and weaker for coho smolts (Figure 4-18). This phenomenon was consistent



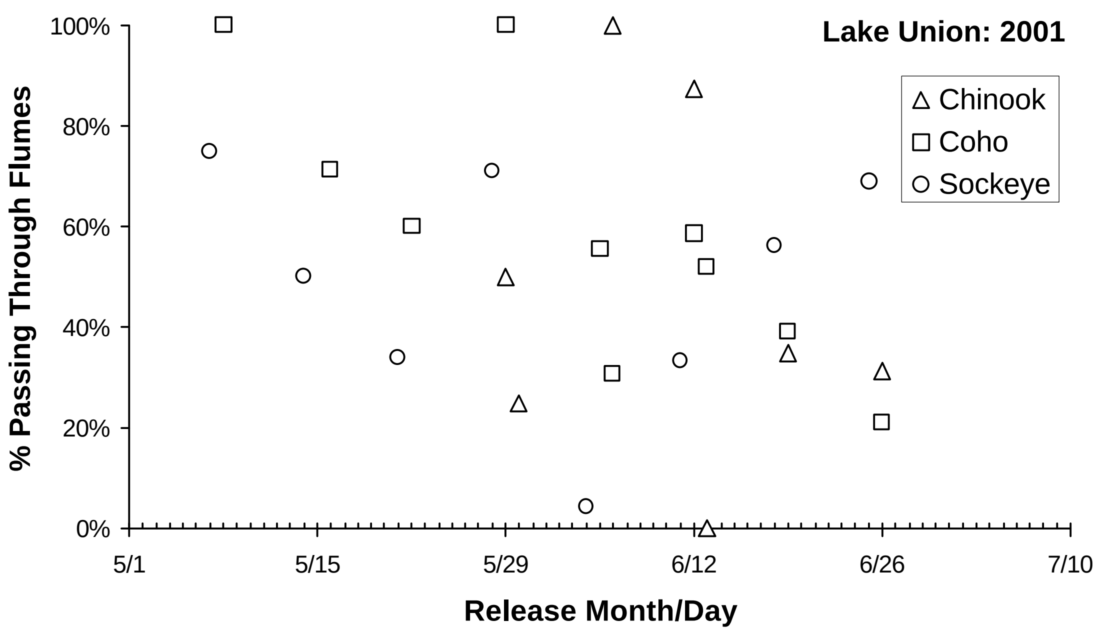


Figure 4-16. Seasonal variation in detection rates in the tunnel readers of juvenile Chinook, coho, and sockeye salmon tagged and released in the LWSC in 2001, Lake Washington GI study. Numbers were adjusted for detection efficiencies.

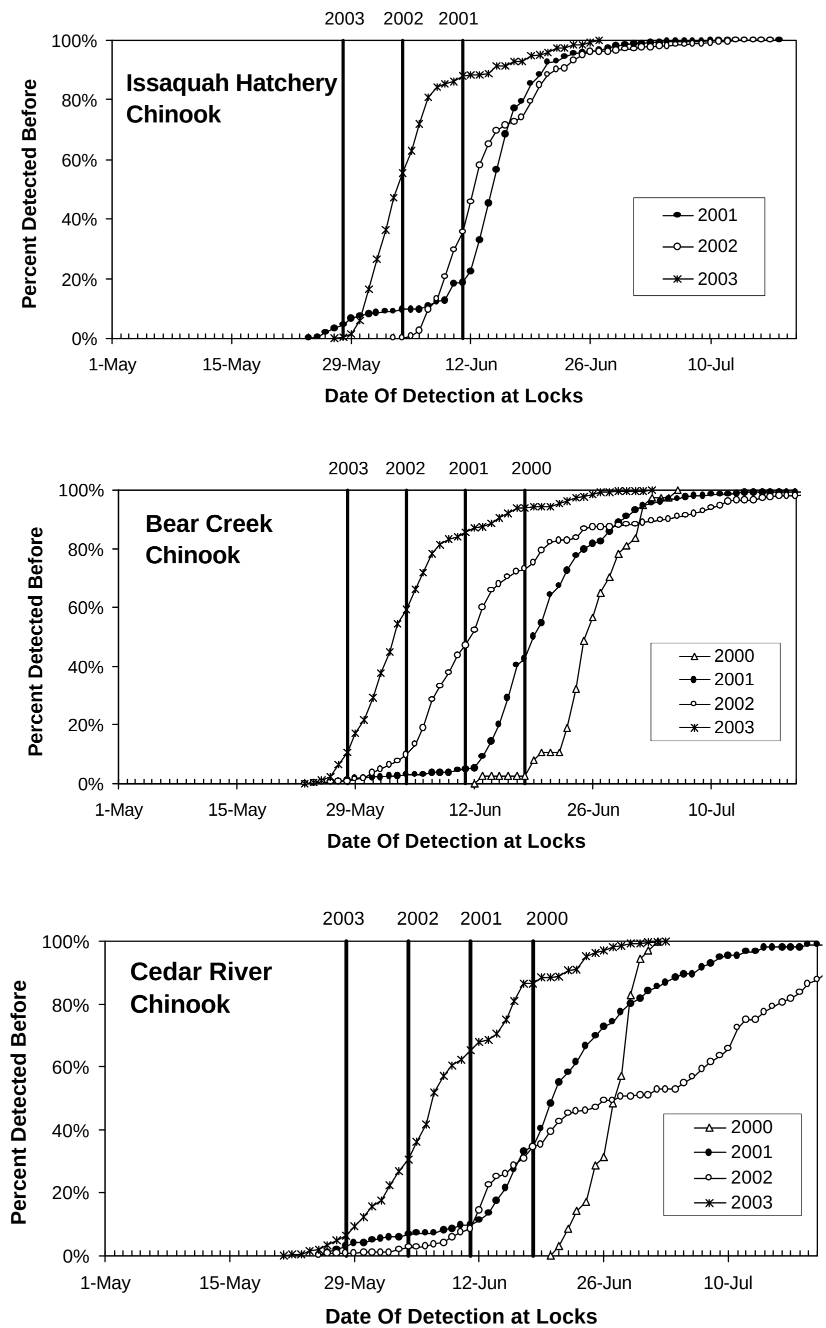
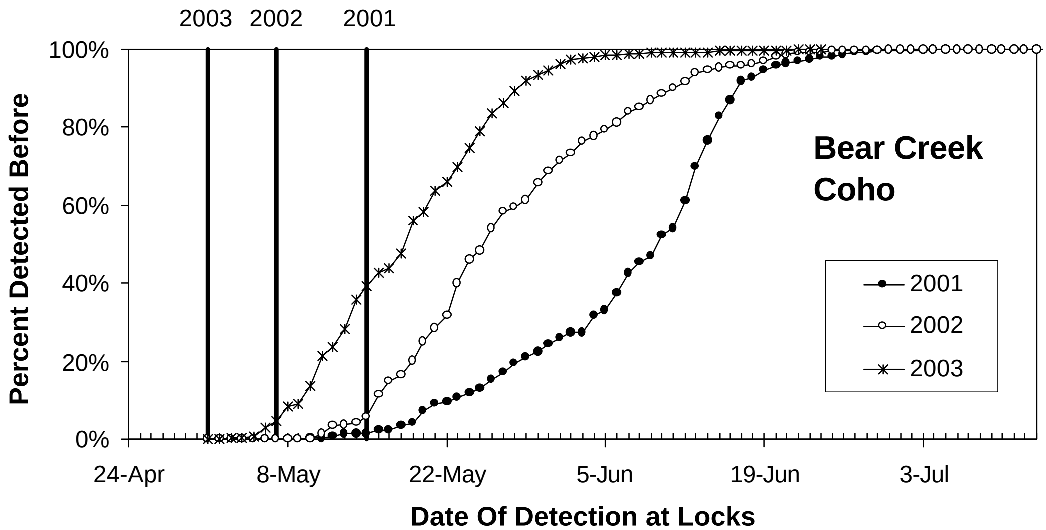


Figure 4-17. Cumulative frequency distributions of the daily numbers of PIT tagged juvenile Chinook salmon from Bear Creek, Cedar River, and Issaquah Hatchery that were detected as they passed the smolt flumes at the Locks in 2000-2003. Dates when the moon was at apogee are indicated for each year by the vertical line.



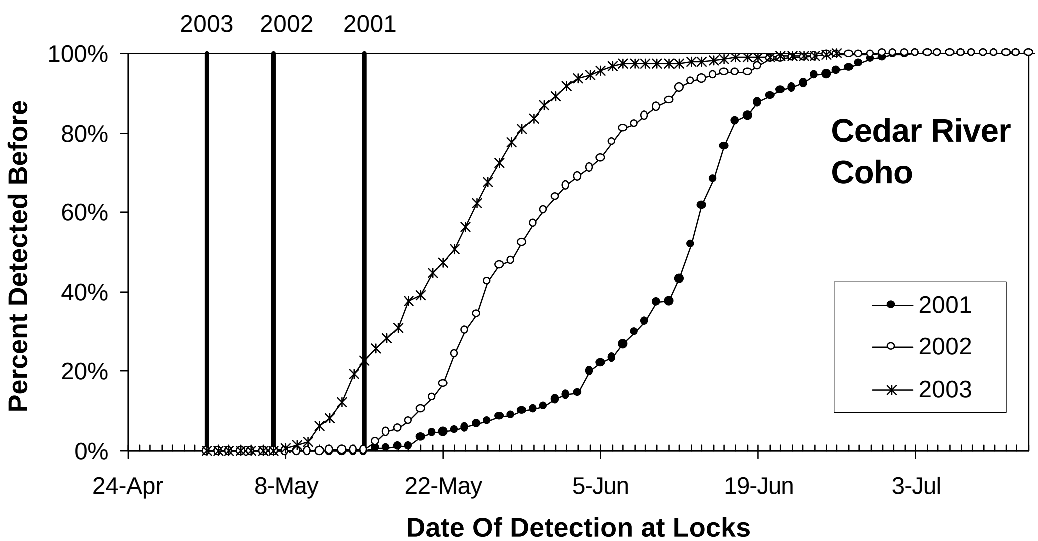


Figure 4-18. Cumulative frequency distributions of the daily numbers of PIT tagged juvenile coho salmon from Bear Creek and Cedar River that were detected as they passed the smolt flumes at the Locks in 2001-2003. Dates when the moon was at apogee are indicated for each year by the vertical line.

across all four years, even as the Julian date of apogee occurred seven days earlier each successive year. Patterns were least clear for sockeye salmon, which were represented by the smallest sample size and exhibited a wider range in timing. However, comparisons of the 2001 PIT tagging length data indicate that of the two year classes present, the older year class (>115 mm TL) passed first in May. The smaller fish (<115 mm) passed around the same time in June as the Chinook salmon run, and exhibited a more prominent association with timing of apogee than did the older year class (see erratum page for 2001 data report, Figure 3-20 in Appendix C).

The reader is referred to DeVries et al. (2004) for a more in-depth discussion of this phenomenon. The relationship may be useful for future forecasting of run timing at the Locks for purposes of adapting operations accordingly.

4.4.5 Travel Times to the Locks

Many fish released in the LWSC were detected relatively quickly in the flumes, within one or two days. Most (>90%) sockeye and coho tagged and released in the LWSC passed the flumes within one and two weeks, respectively, indicating that they did not spend much time milling about in the LWSC before making the transition to saltwater. Migration rates for each species varied between stocks and years, however, where travel time did not consistently reflect travel distance, water temperatures, or location. For example, Chinook tagged farther from the Locks in 2001 migrated faster on average, whereas the opposite was observed in 2002 for the Issaquah Hatchery, Bear Creek, and Cedar River fish (Figure 4-19). Migration rates were faster in 2002 and 2003 overall than in 2000 and 2001 for Chinook (Figure 4-20) and 2001 for coho (Figure 4-21). Tributary instream flows were highest of the four years in 2002, whereas flows in 2003 were lowest on record in some streams (e.g., Issaquah Creek; USGS provisional data). June surface water temperatures in the LWSC were generally coolest in 2002 and warmest in 2003 (Figure 4-5). The variation seen in travel times and migration rates over the four years thus did not appear to reflect a dominant effect of any one variable. In general, migration rates increased slightly on average each year as the passage season progressed, but this reflected mostly increasing variation in travel time of fish tagged later in the season (e.g., Figure 3-16).

4.4.6 Shoreline Affinity Behavior

Results from 2001-2003 have provided cumulative evidence that Chinook salmon smolts exhibit shoreline affinity in Lake Washington and Lake Union while they are migrating, and probably mix across the LWSC within the Montlake and Fremont Cuts and across the upstream side of the

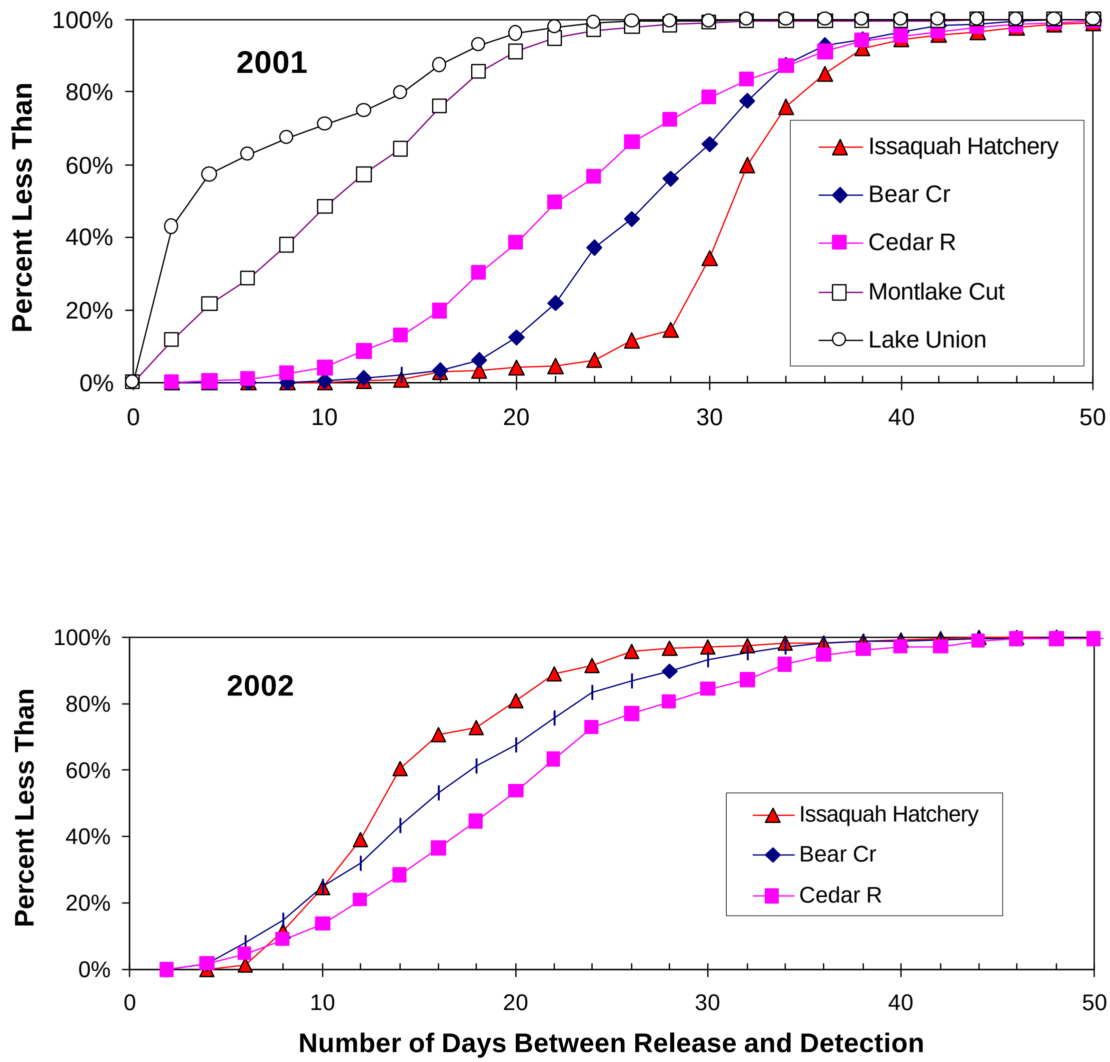


Figure 4-19. Within- and between-year variation in travel time of Chinook salmon as they migrated through the Lake Washington system to the Locks in 2001 and 2002, Lake Washington GI Study.

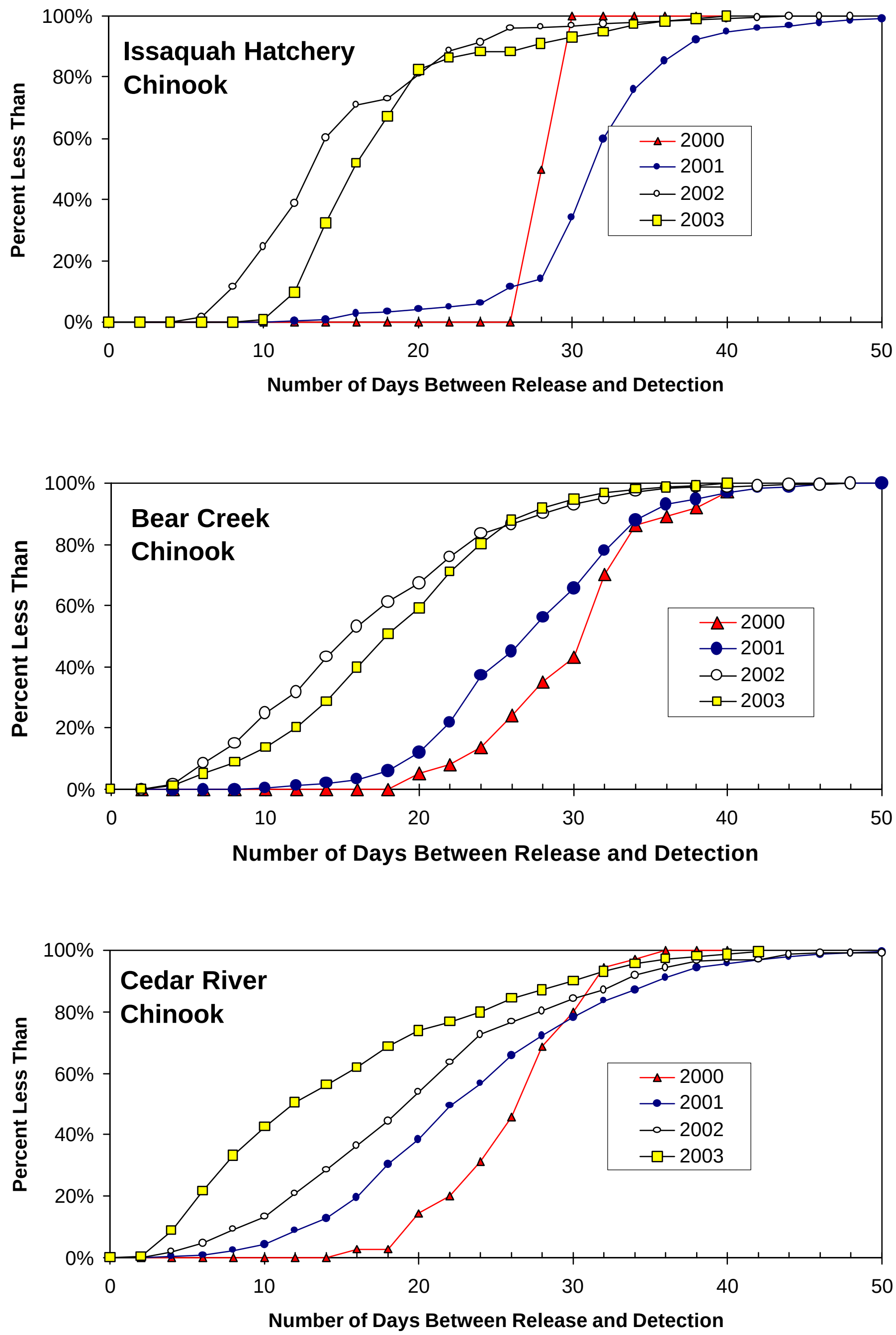


Figure 4-20. Between-year variation in travel time of tributary and hatchery Chinook salmon as they migrate through the Lake Washington system to the Locks, Lake Washington GI Study.

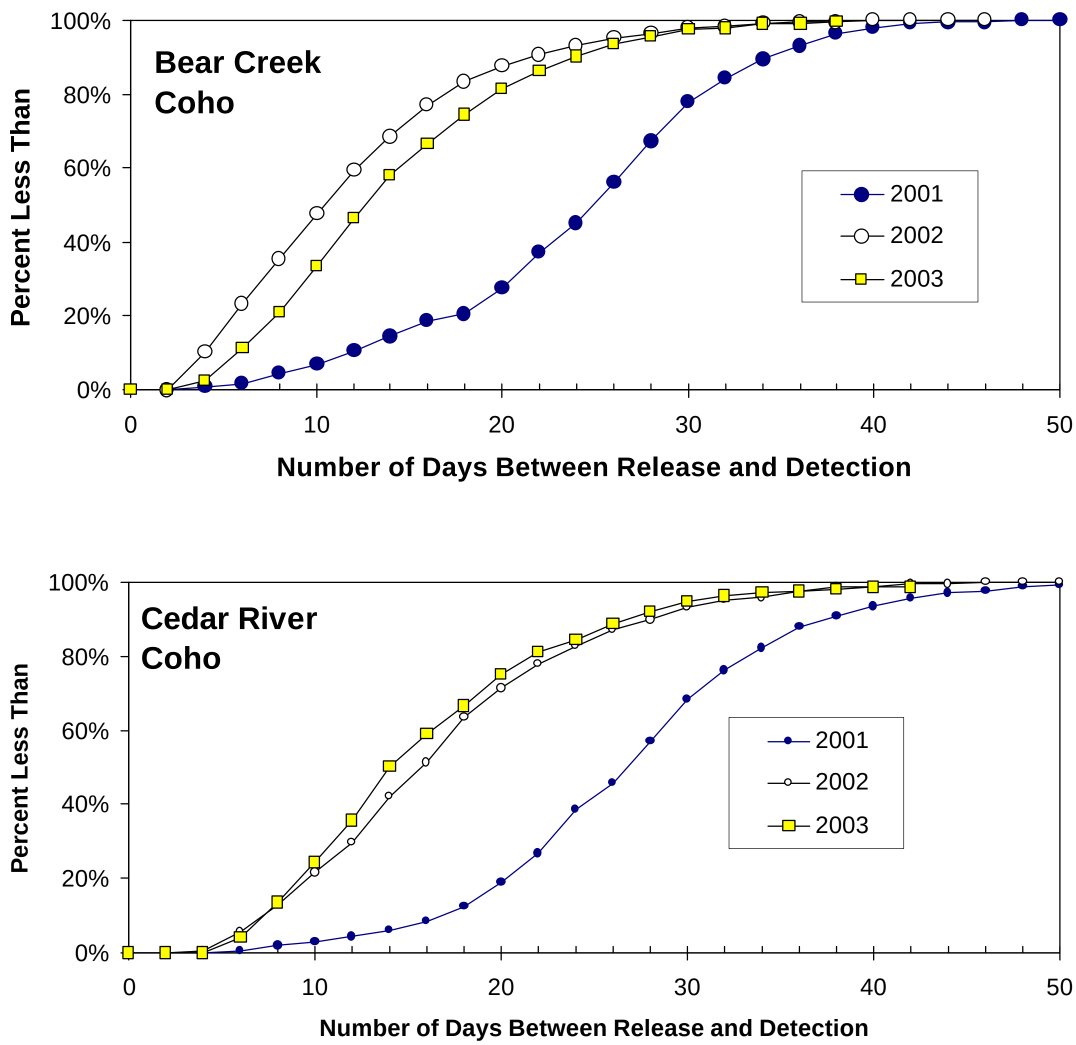


Figure 4-21. Between-year variation in travel time of tributary coho salmon as they migrate through the Lake Washington system to the Locks, Lake Washington GI Study.

Locks. The shoreline affinity test results for 2002 and 2003 combined support this directly (Figure 3-18). The mixing hypothesis is also supported anecdotally by the observation that smolts seem to leap from the water surface everywhere in Salmon Bay immediately upstream of the Locks. Mixing likely occurs when fish reach the Locks because the lock gates are closed at one end most of the time, and the flume entrances present a relatively small opening, so fish may move from one shore to the other as they search for a pathway downstream.

The collective study travel time results provide additional indirect evidence of shoreline affinity within lakes Washington and Union, as described below.

As in 2001 and 2002, hatchery Chinook began showing up in Cedar River trap catches in 2003 within a few weeks of their release. The first was caught on May 31, 2003, twelve days after release into Issaquah Creek. According to the median travel speed for 2003 (~4.8 km/day) and approximate distance including following the eastern shoreline of Lake Washington (~88 km), fish would be expected on average to arrive at the trap location 18 days after release, on or about June 6, 2003. Hatchery Chinook were caught until June 10, 2003 (Lindsey Fleischer, WDFW, personal communication). A fish traveling at the 90th percentile travel speed (~6.3 km/day) would arrive on or around June 2, 2003. Similar patterns were observed in 2001 and 2002 (DeVries 2002, 2003; Lindsey Fleischer, personal communication). The catches of hatchery Chinook smolts in the Cedar River trap in 2001-2003 were thus consistent with a shoreline affinity hypothesis, corresponding to fish that turned left instead of right at the mouth of the Sammamish River.

Similarly, the natural origin Chinook tagged and released in Gene Coulon Park in 2003 took longer (median 23 days) to pass through the smolt flumes than fish tagged and released at the Cedar River trap (median 12 days; Figure 3 -15). Table 3-2 indicates that the approximate travel distance from Gene Coulon Park along the eastern shoreline of Lake Washington is 66 km, whereas it is 39 km from the Cedar River trap following the western shoreline. These distances and travel times are associated with average travel speeds of 2.9 km/day and 3.3 km/day, respectively, which are similar in magnitude. It is thus plausible that the Chinook smolts PIT tagged at Gene Coulon Park were fish that had turned right coming out of the Cedar River and continued to migrate along the eastern shoreline to reach the Locks.

Within the LWSC, the shoreline affinity test group released on the south shore of Lake Union in 2003 took longer to arrive and pass through the smolt flumes than the group released on the north shore. The south shore travel time cumulative distribution in Figure 3-15 is well to the right of the north shore's distribution, whereas the travel speed distributions overlap. Again, this is consistent with a shoreline affinity hypothesis applied to Lake Union.

It is unknown what proportion of fish originating from the Sammamish and Cedar rivers migrate along the eastern shore of Lake Washington, so the migration rate data resulting from the PIT tag studies to date should be considered accordingly. This parameter could be determined through specific capture-recapture studies.

4.5 SYNOPSIS SUMMARY

The following primary observations or hypotheses were made based on the 2000-2003 PIT tag study results. They represent a concise recap of the best available information to date. The observations below do not represent all findings based on the PIT tag data but may be the most noteworthy and provide guidance for focusing future questions. Specific, supporting details and other observations may be found in this report and the 2000, 2001, and 2002 reports.

4.5.1 Survival Estimation

- Survival of Chinook smolts appears to be high (probably close to 100%) in the LWSC during most of the outmigration season, but may decrease when water temperatures exceed somewhere above about 15-19 C.
- Survival estimates in most cases have been of low precision (most 95% confidence intervals spanned more than one quarter of the estimate in magnitude, and many were as big as the estimate itself), and have been complicated by warming water temperatures later in the season.
- PIT tag survival estimates were influenced, at minimum, by proportion using flumes, travel time distributions, residualism, and various sources of natural mortality.
- There is subtle but inconclusive evidence of a potential effect of fish size on detection rate at the Locks later in the outmigration season, where larger Chinook smolts may have a slightly greater probability of passing through the flumes than smaller smolts; however, differences in length frequency distributions of all fish tagged vs. all fish detected were not significantly different in a consistent manner for all Chinook stocks.

4.5.2 Migration Behavior in Freshwater

- Average migration rates vary spatially, seasonally, and annually. Travel times to the Locks generally, but not consistently, reflect travel distance and vary within (annually) and between (spatially) stocks.
- Average Chinook smolt migration rates tend to increase as the outmigration season progresses; coho rates are steadier.
- Chinook smolts appear to move along shorelines while outmigrating.
- Chinook smolts may mix cross-channel in the LWSC in the Montlake Cut, Fremont Cut, and Locks forebay area.
- Sockeye smolts spend least time in the LWSC (in general, most within one week), Chinook smolts the most (most within three to four weeks); coho are intermediate (most within two weeks).
- Sockeye salmon smolts passing the Locks represent two age classes (young of year and yearlings).
- Chinook and coho salmon smolts have also been found to residualize in the system, with rates ranging between 0.09% and 0.26%.
- Yearlings of all three salmon species and University of Washington young of year Chinook generally pass through the Locks earlier than young of year Chinook and sockeye smolts; the distinction may reflect fish size.
- Smolts may have a higher probability of residualizing in Lake Washington as the outmigration season progresses and surface water temperatures warm. The Montlake Cut may pose a thermal barrier later in the season.

4.5.3 Passage at the Locks and Lock Operations

- The proportion of fish using the flumes relative to other routes through the Locks is initially approximately steady, can be on the order of 40-80% when all four flumes are open, and then decreases over time. The seasonal decrease appears to reflect warming surface water temperatures in the LWSC, decreasing flume flow rate, and a vertical shift by outmigrants to deeper, cooler water.
- Late in the outmigration season, most Chinook smolts likely pass through the deeper, large lock.

- Relatively few smolts pass through the flumes during the night; the greatest passage rates generally occur near dawn, which may reflect an accumulation of smolts arriving overnight.
- Passage rates through the flumes increase during small and large lock fillings compared with between-fill periods.
- Diurnal patterns in passage rates through the flumes may best reflect frequency of small lock operations.
- The number of smolts passing through the flumes increases with total flow rate through the flumes, on average.
- The small flume (4A) generally passes small numbers of smolts when operated alone in Gate 4.
- Passage rates may increase in a flume (other than the small flume) when its companion flume in the gate is shut off (i.e., a compensatory passage rate effect may exist).
- Water savings can most likely be achieved by (i) turning off the flumes at night, and (ii) shutting down the flumes when surface water temperatures regularly exceed some (to be determined) threshold value between 19-21 C, when flume passage rates become minor.
- Some Chinook and coho smolts recycle upstream through the large or small lock with observed rates ranging between 0.06% and 0.70% for fish originating in tributaries; no sockeye smolts have been observed to recycle. The time between repeat passage decreases as the outmigration season progresses.
- Chinook released into the LWSC from the University of Washington Hatchery and the Issaquah Hatchery exhibited the strongest recycling behavior.
- Passage/estuarine entry of young of year Chinook and sockeye smolts appears to be initiated in response to lunar apogee or quarter moon.

4.5.4 Estuarine Transition

- Smolts may spend little time (e.g., less than an hour) in the freshwater lens immediately below the locks.
- Sockeye smolts appear to spend least time in the inner bay, Chinook smolts the most; coho may be intermediate.

- Hatchery Chinook may reside longer in the inner bay below the Locks than natural origin Chinook, possibly reflecting an abundant food supply from the LWSC.

4.6 FUTURE STUDY RECOMMENDATIONS

The following possible changes to study design are suggested on the basis of the data collected the last three years, and accompanying justifications are given:

- The structural vibration and surging problems continue to result in decreased detection efficiency in the large flumes (4B and 5B), albeit to a lesser extent than in 2000. It is important to continue working toward increasing the detection efficiency to above 95% as much as possible to reduce this source of variation to a negligible level. One possibility is to experiment with hydraulics within the flumes to reduce pulsing and smooth out the water surface within the tunnel readers and the flume flow lines.
- Calibration testing should continue with both tagged fish and the "fish sticks" to further evaluate stick performance relative to using live fish because results to date indicate large variability remains when using fish sticks, but use of live fish is more expensive. Stick tests should be done frequently to identify the potential need for retuning of selected tunnel reader coils. Additional tests would be useful comparing a prototype approach developed by the author in 2004 involving a string of sticks introduced to the flumes and recovered at the outlet using rod and reel and a long gaff. If effective, the method would eliminate the need for a boat to recover sticks downstream, thereby reducing effort and cost of calibration testing.
- Limited calibration test results in 2002 and 2003 indicate that live, tagged, hatchery fish can be introduced into each flume from the spillway walkway by flushing them through a large diameter PVC pipe using buckets of water, rather than through the more time consuming hand-feeding into the face of the flume from the bow of a boat. Recycling of large numbers of calibration test fish in 2003 indicate that the method may not result in significant harm to the specimens. Ideally, fish should be flushed individually and in groups to simulate a range of observed passage patterns. However, considering tag cost and holding facility limitations, at minimum the fish should be flushed down the pipe one at a time to maximize detection probability (it is unlikely based on the four years of data that more than one PIT tagged fish arriving from upstream passes through a flume at any moment in time and precludes detection of another tag).
- Future tag purchases should be of the newer “supertag” type only, given their greater detection rates at the flumes than of standard tags.

- Fish should be held at the Metro Laboratory primarily for calibration testing and releases at that location. Holding capacity could be increased in the future (F. Sweeney, King County/Metro, personal communication). Other objectives should rely on other sources of fish. Holding of Chinook at the UW hatchery is not recommended for future PIT tag studies because of stress and disease problems experienced in previous years as water temperatures warm in the LWSC.

- Future tagging of fish at the Issaquah Hatchery is recommended only if fish can be released in smaller groups over the course of the migration season to better evaluate survival, migration, and passage characteristics of fish originating in Issaquah Creek. The one-time release at the hatchery each year in 2001-2003 has proven useful, but it is unlikely extensive, additional, useful information can be derived from future such releases beyond identifying long term trends.

- As long as funding is available to run the Bear Creek and Cedar River screw traps, they could continue to be used to tag fish if tags are made available (D. Seiler, WDFW, personal communication).

- Efforts in 2003 indicated that transporting hatchery fish from Issaquah Hatchery to different release locations in Lake Washington tributaries and tagging them onsite prior to release was a difficult endeavor as water temperatures warmed (see report in Appendix A), so continued tagging of fish at the location of capture remains recommended as the most direct means for addressing survival, migration, and passage characteristics. Ideally, PIT tagging should occur at a number of locations along the migration route to evaluate differential survival at different locations, but only when Lake Washington and LWSC water temperatures are forecasted to be average or cooler in the month of June. Future studies should be set up with the contingency that if the spring water temperatures are predicted to be high, that the study be postponed until the following year(s) when water temperature are more conducive to post-tagging survival in June. Such information would be valuable for identifying measures at specific locations intended to increase overall survival. At minimum, purse seining could be continued in Lake Union and in the vicinity of the Montlake Cut to evaluate survival in the LWSC. In contrast to 2000 when there were disease problems, and 2003 when there were likely water temperature-related post-tagging mortality problems, the 2001 and 2002 data suggest minor mortality occurred in the LWSC. Further study would be useful for evaluating factors of decline, particularly upstream of the LWSC.

- Beach seining below the Locks to recapture PIT tagged fish is not recommended at this time for purposes of estimating proportions using the flumes. Significant mortality and injury could be expected.

- Sampling could conceivably be conducted in the large lock and small lock to determine the proportion of PIT tagged fish passing through each, as well as provide better information on recycling patterns through the Locks. Because less water is used to fill the small lock than the large lock, it is possible that relatively less effort could be expended in the former. However, the data would mostly re-confirm that recycling takes place, which appears to be determined more thoroughly based on the tunnel reader detections. Considerable sampling effort would likely be needed if the data from the two locks were to be used to determine the proportion of tagged fish using that route.
- Recently installed adult PIT tag readers in the fish ladder will make it possible in future years to scan for PIT tagged smolts, to determine the proportion of fish using that route.
- If tagging is continued in the LWSC, each day's collection of tagged fish should be divided in two and each group released near the north and south shorelines, to continue evaluating shoreline affinity and proportion using the smolt flumes. Alternatively, hatchery Chinook could be held at the Metro Laboratory and released at that location at a minimum. Doing this over the passage season would facilitate an evaluation of seasonal changes in the proportion using the smolt flumes, and thus an improved appreciation of the temporal variation in survival or residualization of outmigrants in the Lake Washington system.
- The influence of small and large lock operations on passage rates should be investigated by alternating between a normal daily lock opening pattern, when each lock is opened more frequently during the day than the night, and a uniform distribution where the frequency of lock openings is similar during both day and nighttime hours. Diurnal passage rate distributions should reflect the respective lock opening patterns tested if there is a relation between lock opening frequency and passage rate.
- The blood of subsamples of PIT tagged fish passing through the flumes could be tested for stress and signs of osmotic change or smolt readiness. This information is important for evaluating the effects of the Locks with respect to the relatively sudden transition to saltwater. Both smolt readiness (e.g., gill ATP-ase, sodium levels) and stress (e.g., plasma cortisol) measures would be required to determine if the fish caught in beach seine samples were experiencing stress from rapid transition to saltwater because they were not completely ready to do.
- Other studies that would be informative and potentially lead to specific recovery-related actions include:
  - Determining proportion of fish migrating left or right upon exiting the Sammamish and Cedar rivers. This could be accomplished by standard capture-recapture techniques.

  - Changes in migration depth in both Lake Washington and the LWSC with increasing water temperature over the course of the migration season. This would help identify more conclusively the relations between water temperature, habitat use during the outmigration, residualization, survival, and passage routes. In addition the results could be evaluated in the context of predator depth and feeding intensity to determine if there is habitat segregation and when predation effects are greater. Migration depth of natural Chinook could conceivably be addressed either by using smaller microacoustic tags than are currently available, or by experimental designs involving diving surveys.

- A small number of tagged fish were detected at the Locks each year that were not in the tagging files. Most appeared to have been missed during scanning at time of tagging. It was possible to resolve where and when they were tagged in most cases by noting tag packaging identification numbers during tagging, and identifying the bag that a tag originated from. However, there were also a small number of tags with numbers not part of the study sequence. Some were identifiable in the PTAGIS database and appeared to have been leftover tags from the Columbia River and were assumed to have been used inadvertently by NMFS in this study during 2000 or 2001. Others were not in the database and were not part of the tag sequence from the GI study; they were considered "mystery" tags, and may have been from another study. These occurrences are mentioned mainly to alert researchers using PIT tags of the possibility for missed tags in any study, and to recommend that they register their tags with the PTAGIS database in Portland, Oregon.

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APPENDIX A

2003 PIT Tagging Activity Summary Reports of:

1. L. Fleischer (WDFW)
2. P. Lawson (Parametrix, Inc.)

Lake Washington Watershed PIT Tagging, 2003

Lindsey Fleischer

Washington Department of Fish and Wildlife
Olympia, Washington 98501-1091

April 2004

Methods

Downstream migrants captured at the Cedar River and Bear Creek rotary screw traps were PIT tagged from late April through early July 2003. The tagging station was set up daily on the banks at both locations: on the cement wall at Cedar River just upstream of the Logan Street Bridge and on the railroad trestle at Bear Creek just downstream of the Redmond Way Bridge. Chinook, coho, and steelhead smolts were tagged at both traps. Healthy fish in excess of 70 mm were tagged. Smolts with physical injuries, descaling greater than 20%, parasites, and predator marks were not tagged. Fish were anesthetized in a solution of one gram of MS-222 per five gallons of water in preparation for tagging. The tag was inserted by syringe into the abdomen approximately halfway between the pectoral and pelvic fins. Size (fork length) and other physical data, such as scale loss, bleeding, and wounds, were recorded for each fish. Fish were held for recovery observation before being released. To estimate mortality and tag retention rates, groups of tagged fish were held for 24 hours. Fish were placed in a perforated five-gallon bucket with a lid, and tied off to the trap suspended in flowing water. Small perforations in the bucket and lid allowed current to flow through the container, but were small enough to retain fish and any tags. The next day fish condition was assessed and the container was examined for lost tags.

Results

Tagging began on April 29 and continued through July 2. Coho smolts were tagged April 29 through May 20, and Chinook smolts were tagged May 1 through July 2. Tagging occurred Monday through Friday during the morning hours. Beginning June 18, tagging occurred only on Mondays, Wednesdays, and Fridays due to low numbers of fish. Fish were held in live wells from the previous morning to increase the number of fish tagged.

Cedar River

In total, we tagged 2,929 smolts: six hatchery and 1,891 wild Chinook, 1,027 coho, four steelhead, and one sockeye (Table A-1). The Chinook total includes 165 smolts tagged on May 8 that were caught by USFWS using a beach seine at Gene Coulon Memorial Beach Park. The park is located along the shore of Lake Washington, just east of the mouth of Cedar River. An additional two fish were tagged; one coho tagged on April 29 or 30, and one unknown species tagged on May 6 or 7. The tag codes of these fish were not found in the tag files, but were detected going through the Ballard Locks.

On May 14, 18 Chinook and 45 coho smolts were held to assess mortality and tag loss. No fish died and no tags were lost. Due to dry, warm weather and high water temperatures, this was the only test for mortality and tag loss at the Cedar River in 2003. Mortality and tag loss is estimated to be less than 1% based on testing in 2001 and 2002.

Bear Creek

In total, 4,349 fish were tagged throughout the season (Table A-1). The number of age 0+ Chinook tagged was 2,305, and 2,040 age 1+ coho were tagged. No steelhead smolts were tagged in 2003. An additional three fish were tagged; one coho was tagged on April 29, and two unknown species tagged on May 6 or 7 and May 16. The tag codes of these three fish were not found in the tag files, but were detected going through the Ballard Locks.

Four duplicate tag codes, not distinguished as recaptures, were discovered in the tag files. Three of these duplicates occurred the day after the original tagging and similar fork lengths were recorded for each tag code. Those three tags were assumed to be recaptures. The forth tag occurred two days after tagging, and one day after the first recapture, however, the fork length was 18 mm greater than recorded on the original tag file. The difference in recorded fork lengths was probably measurement error, and the duplicate tag code was assumed to be a recapture.

On May 14, 25 Chinook and 25 coho smolts were held to assess mortality and tag loss. No fish died and no tags were lost. Due to dry, warm weather and high water temperatures this was the only test for mortality and tag loss at Bear Creek in 2003. Mortality and tag loss is estimated to be less than 1% based on testing in 2001 and 2002.

Table A-1. Smolts PIT tagged at Cedar River and Bear Creek screw traps, 2003.

Date	Bear Creek[a]		Cedar River[b]				
	Chinook	Coho	Chnook Wild	Chnook Hatchery	Coho	Sockeye	Steelhead
04/29/03		347			50		
04/30/03		240			102		
05/01/03	4	155	17		62		
05/02/03	21	248	18		84		
05/05/03	64	205	24		61		
05/06/03	31	100	19		150		
05/07/03	65	100	34		94		
05/08/03	71	100	[c]165		46		
05/09/03	131	100	27		99		
05/13/03	74	95	21		37	1	
05/14/03	59	100	18		45		
05/15/03	67	100	0		0		
05/16/03	172	100	110		155		2
05/17/03	100		16		42		
05/19/03	100		67				
05/20/03	149	50	39				
05/21/03	146		22				
05/22/03	128		21				
05/23/03	32		42				
05/27/03	50		42				
05/28/03	43		40				
05/29/03	40		43				
05/30/03	156		35				
06/02/03	63		56				
06/03/03	40		100				1
06/04/03	50		56	1			
06/05/03	50		93	5			
06/06/03	39		50				
06/09/03	33		100				
06/10/03	15		59				
06/11/03	34		79				
06/12/03	54		94				
06/13/03	18		68				1
06/16/03	41		87				
06/17/03	29		23				
06/18/03	26		39				
06/20/03	26		69				
06/23/03	20		9				
06/25/03	16		53				
06/27/03	18		11				
06/30/03	24		5				
07/02/03	6		20				
Total	2,305	2,040	1,891	6	1,027	1	4

[a] Totals do not include three additional tags: one coho tagged on 4/29, and two species unknown tagged on 5/06 or 5/07 and 5/16.

[b] Totals do not include two additional tags: one coho tagged on 4/29 or 4/30, and one unknown species tagged on 5/06 or 5/07.

[c] Chinook caught, tagged, and released at Coulon Memorial Park near the mouth of the Cedar River.

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Lake Washington Watershed PIT Tagging, 2003

Pete Lawson

Parametrix, Inc.
Kirkland, Washington

February 2004

Methods

Outmigrating juvenile Chinook salmon were captured and PIT tagged at three general locations; the Sammamish River, Lake Washington, and Lake Union. Tagging of fish occurred in May and June of 2003. Two locations on the Sammamish River, an upstream site and a downstream site, were chosen for the study. The first site was near the mouth of the river, adjacent to the WDFW Boat Launch off 68th Avenue NE (Kenmore site). The second site was located on the property of the Sammamish Rowing Association in Redmond, Washington, immediately adjacent to the dog walk area at Marymoor Park (Marymoor site). At both of these sites, beach seining was used to collect migrating Chinook salmon. From two to five consecutive beach seine sets were deployed each day of tagging on the river, and the fish were combined in a holding barrel for sorting and tagging. As numbers of migrating Chinook were absent or very low during the first month of tagging, juvenile Chinook from the WDFW Issaquah Hatchery raceways were transported to the Sammamish River sites, and tagged and released. This method was used to supplement the number of fish collected by beach seining if beach seining did not yield enough Chinook to meet the target sample size. The hatchery fish were transported to the site the day before tagging operations, and maintained in 40-gallon tubs with either flow-through fresh water pumped from the river, or, if river water temperatures were high, chilled and oxygenated (using double-bagged block ice, O_2, and airstones) hatchery water oxygenated with tanks and airstones. The tagging station was set up on the river bank at both locations. Specifically, on the property of Plywood Supply Company (Kenmore site) and near the boat launch of the Lake Sammamish Rowing Association (Marymoor site).

A purse seine, provided by WDFW and crewed by WDFW staff, was used to collect fish in Lake Washington and Lake Union. The Lake Washington collection sites included the area immediately east of Madison Park, and the areas south, west, and north of Webster Pont. Fish collected from Lake Washington were transferred to a boat and transported to Madison Park, where the tagging station was set up on the shore. Multiple purse seine sets were usually required to collect the number of Chinook required by the protocol. In Lake Union, purse seining occurred north of Gasworks Park, and fish were transported to the Police dock (adjacent to gasworks Park), where the tagging station was set up inside a boathouse.

Healthy Chinook salmon of wild and hatchery origin, in excess of 70 mm, were tagged at all sites. A small number of coho salmon (at Kenmore) and sockeye salmon (from Webster Point) were also tagged. Smolts with obvious physical injuries (e.g. descaling greater than 20 percent, parasites, and predator marks) were not tagged. Prior to tagging, fish were anesthetized in a solution of MS-222 at a concentration of 30 mg/L (ppm). The tag was inserted by syringe into the abdomen approximately halfway between the pectoral and pelvic fins. Size (fork length), fish origin (hatchery or wild stock based on the presence or absence of the adipose fin), and other physical data, such as scale loss, bleeding, and wounds, were recorded for each fish. Fish were held for recovery observation before being released.

Results

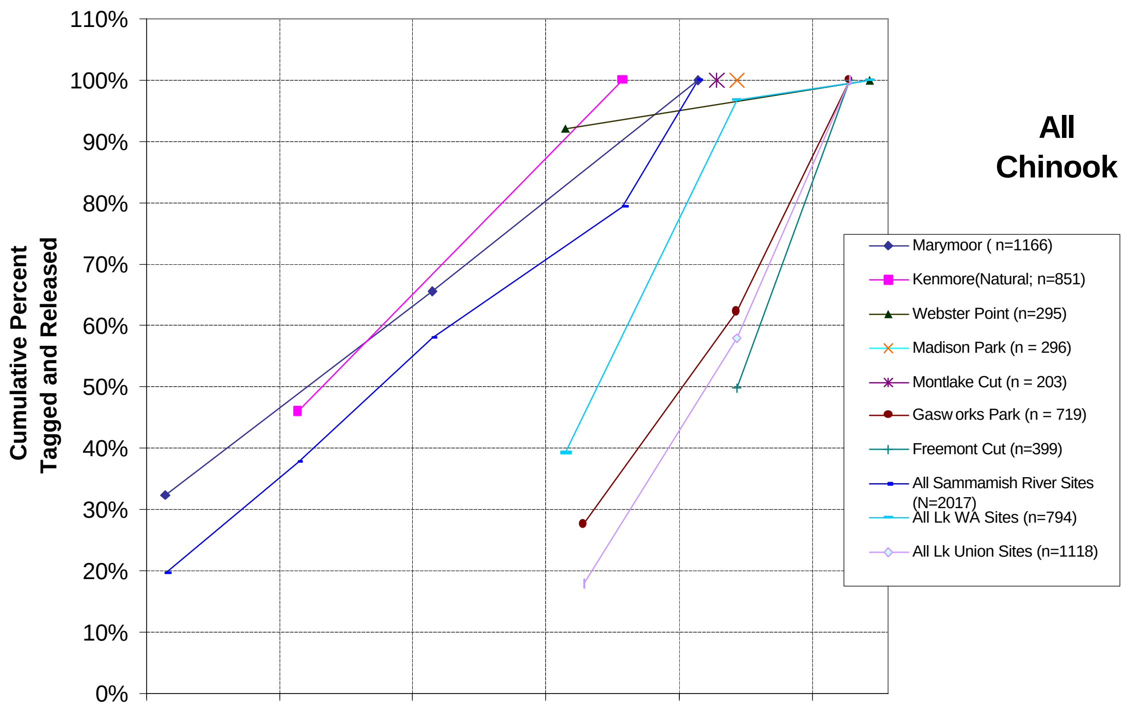

Figure A-1. Cumulative frequency distributions of juvenile Chinook salmon PIT tagging numbers by date and location in the LWSC, Lake Washington, and the Sammamish River, 2003 Lake Washington PIT Tagging study.

Sammamish River

Tagging occurred a total of five times, in the morning hours (0430 to 1000) beginning on May 6 and continuing through May 30. We tagged 1,166 smolts (763 hatchery transfer Chinook, 403 run-of-the-river Chinook) at Marymoor and 811 smolts (351 hatchery transfer Chinook, 410 run-of-the-river Chinook, 50 coho) at Kenmore for release in the Sammamish River (Table A-2). Of these fish there were 4 known tagging mortalities (Table A-2), indicating a Chinook mortality rate of 0.2 percent. One tagged Chinook was recaptured at the Kenmore site on May 30 (Table A-2). Tagging efforts were scheduled on the Sammamish River for the weeks of June 9 and June 16, but not undertaken due to high water temperatures in the Sammamish River (19 to 22^{o} C) during that period. Beach seining did occur at the Kenmore site on June 25 (water temperature of 17^{o} C) but no fish were tagged because only 4 Chinook were caught with 4 seine sets and no Chinook from the Issaquah hatchery were available for tagging.

All of the first three tagging efforts on the Sammamish River sites involved the release of hatchery transfer Chinook only (due to the lack of outmigrating juvenile Chinook in the river), while the final two successful tagging efforts involved run-of-the-river Chinook. In the latter cases, water temperatures within Lake Washington and the LWSC were already at or above 17°C. Thermal stress, handling stress, or a combination of the two may have caused post-release mortality that contributed to the apparent low survival rates (to the Locks) exhibited by these fish.

Lake Washington

Tagging occurred a total of three times, in the morning hours (0800 to 1100) beginning on May 14 and continuing through June 12. From Lake Washington 794 run-of-the-river Chinook smolts were tagged for release at Webster Point and the east end of Montlake Cut (Table A-2**)**. In addition, 369 sockeye salmon collected at Webster Point were tagged at Magnuson Park. The sockeye were released at Magnuson Park due to high wave conditions and high tagging fish mortality (32 mortalities, 8.7 percent). Of the Chinook collected in Lake Washington, there were approximately 45 tagging mortalities (Table A-2), indicating a Chinook mortality rate of 5.7 percent. One tagged Chinook was recaptured at the Webster Point site on May 27 (Table A-2). Purse seining occurred on May 21, but no Chinook were captured. On June 16, a total of about 200 Chinook were seined offshore of Webster Point, but tagging efforts were aborted in an effort to avoid fish mortalities. These fish were released untagged after showing symptoms of extreme physical stress after only 5 minutes in captivity. The surface lake temperature at that time was approximately 20^{o} C.

Previous PIT tagging studies have indicated that when water temperatures increase to 17 to 18ºC, there is a significant increases in Chinook salmon smolt mortality during PIT tagging operations (S. Achord *in* DeVries et al. 2002). Furthermore, we believe that fish captured by purse seine likely undergo higher levels of stress than do fish captured by beach seine or those transported to the tagging site directly from a hatchery and then acclimated overnight prior to tagging. Purse seined fish undergo a greater amount of handling in the process of sorting the fish, removing the fish from the nets, and transporting the fish by boat to the tagging site. In most cases, multiple (3 to 7) seine net sets were required to collect the target sample size. Although efforts were made to minimize the handling of fish, observations indicated that purse seined fish had higher de-scaling rates than non-purse seined fish. We believe that a combination of high water temperatures and greater handling effort may have been the cause of the higher mortality rates observed for Chinook sampled in Lake Washington and Lake Union, versus those fish sampled in the Sammamish River (Table A-3). Mortalities observed at release were higher for those fish collected from Lake Washington and it is probable that post-release mortality of fish captured by purse seine in the lake were also higher, perhaps substantially so.

Table A-3. Comparison of PIT Tagging Release Mortality and Water Temperature

Date	Capture Location	Release Location	Capture Method	Post-tagging Mortality (Percent)	Water Temperature (^{o}C)
5/6/2003	Marymoor Park	Marymoor Park	Hatchery transfer	0.0	12.0
5/13/2003	Kenmore	Kenmore	Hatchery transfer	0.2	16.5
5/14/2003	Webster Point	Magnuson Park	Purse seine	8.7	15.3
5/20/2003	Marymoor Park	Marymoor Park	Hatchery transfer	0.0	14.4
5/27/2003	Webster Point	Webster Point	Purse seine	12.9	15.6
5/28/2003	Gasworks Park	Gasworks Park	Purse seine	0.0	15.6 (surface); 14.4 (10 m below surface)
5/30/2003	Kenmore	Kenmore	Beach seine	0.0	17.2
6/3/2003	Marymoor Park	Marymoor Park	Beach seine	0.8	15.6
6/4/2003	Webster Point	Madison Park	Purse seine	0.0	16.7
6/4/2003	Webster Point	East of Montlake Cut (next to UW shell house)	Purse seine	4.9	16.7
6/5/2003	Gasworks Park	West End of Fremont Cut	Purse seine	3.0	17.2
6/5/2003	Gasworks Park	Gasworks Park	Purse seine	4.8	17.2
6/11/2003	Gasworks Park	West End of Fremont Cut	Purse seine	2.0	18.9
6/11/2003	Gasworks Park	Gasworks Park	Purse seine	0.4	18.9
6/12/2003	Webster Point	Webster Point	Purse seine	0.0	18.3
			Mean for Sammamish River Sites	**0.2**	**15.1**
			Mean for Lake Sites	**4.4**	**16.8**

Lake Union

Tagging occurred a total of three times, in the morning hours (0800 to 1100) beginning on May 28 and continuing through June 11. From Lake Union, 1,118 run-of-the-river Chinook smolts were tagged for release off Gasworks Park, and at the west end of the Fremont Cut (Table A-2**)**. Among these fish, there were 23 tagging mortalities (Table A-2), resulting in an initial tagging mortality rate of 2.1 percent. One previously tagged Chinook was recaptured at the Gasworks site on June 11 (Table A-2). Concerns over post-tagging tagging mortalities due to high water temperatures and from stress resulting from handling of the fish collected in Lake Union are similar to those discussed for fish collected from Lake Washington.

Summary

During the sampling period, a total of 4,258 smolts (2,725 Chinook, 1,114 hatchery transfer Chinook, 389 sockeye, and 50 coho) were tagged over the entire study area. No observed tag loss was noted. Over the course of the study there were approximately 104 tagging mortalities (about 72 Chinook and 32 sockeye), indicating an overall study mortality rate of 2.4 percent. The mortality rate for Chinook salmon was slightly lower at 1.9 percent. Much of this mortality can be attributed to unusually high seasonal water temperatures in the Sammamish River and Lakes Washington and Union, particularly in the month of June. In June, water temperatures during capture operations ranged between a low of 15.5°C to a high of near 20°C. Water temperatures rose even higher in the Sammamish River, up to 21.7°C, but no tagging was undertaken on these days due to concerns about high tagging mortality due to extreme thermal stress. There were a total of 4 recaptured pit-tagged fish, including one transferred from the Issaquah Hatchery, caught between May 20 and June 11 (Table A-2). Overall, post-tagging mortalities were much higher in fish collected from the two lakes, as compared to those collected or released at the Sammamish River sites (Table A-3). There was concern over post-tagging tagging mortalities from fish collected in Lake Union and Lake Washington due to the combination of high water temperatures and the degree of handling required to capture, tag, and release fish.

Future PIT tagging studies could incorporate the simultaneous release of equal numbers of run-of-the-river and hatchery transfer fish. This would allow the direct comparison of survival rates between these two groups and may aid in narrowing down the specific stresses (i.e., handling or thermal stress) that contribute to post-release mortality. In addition, the data may help to elucidate differences in migration timing between capture/release and hatchery transfer Chinook salmon.

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Table A-2. Summary of tagging operations by date and location in the LWSC, Lake Washington, and the Sammamish River, 2003 Lake Washington PIT Tagging study.

Date	**Capture Location**	**Release Location**	**Method of Wild Fish Capture**	**Total Number of Fish Tagged**	**Number of River Run Chinook Tagged**	**Number of Hatchery Transferred Chinook Tagged**	**Number of Other Salmon Species Tagged**	**Live Tagged Fish Successfully Released**	**Post Tagging Morts**	**Mortality Percentage**	**Tag Lot Numbers**	**File Names**	**Comments**
5/6/03	Marymoor Park	Marymoor Park	Beach Seine (3 sets)	377	2	375	0	377	0	0.0	C750440 C750441 C750442 C750443	FAG03126.MMB FAG03126.MMH	Beach seine captured 2 wild Chinook, 178 coho (>98% fin clipped), 2 cutthroat, 1 stickleback, and 1 sculpin; 19 tags left in last lot (C750443) will be used for future Marymoor Taggings.
5/13/03	Kenmore	Kenmore	Beach Seine (4 sets)	401	0	351	50	400	1	0.2	C750446 C750447 C750448 C750449 C750445	FAG03133.KMB FAG03133.KMH	Beach seine captured 0 wild Chinook, about 50 coho (>98% fin clipped) were tagged (FAG03133.KMB), 5 cutthroat, numerous sticklebacks and sculpins, and a few juvenile chum and sunfish; The 90 tags left in last lot (C750445) will be used for future Kenmore Taggings.
5/14/03	Webster Point	Magnuson Park	Purse Seine (1 Set)	369	0	0	369	337	32	8.7	C750444 C750450 C750451 C750452	FAG03134.WEB	Purse seine captured several thousand wild sockeye, about 50-100 larger coho, 0 wild Chinook, about 50 coho and numerous sticklebacks. The 36 tags left in these lots (combination of all vials) will be used for future Webster Taggings. **Tagged 365 wild sockeye w/32 post-tagging morts.** Released at Magnuson due to weather difficulties and high levels of fish stress.
5/20/03	Marymoor Park	Marymoor Park	Beach Seine (3 sets)	389	1	388	0	389	0	0.0	C750443 C750453 C750454 C750459 C750455	FAG03140.MMH	Beach seine captured 1 wild Chinook, 80-100 coho (>98% fin clipped), 1 bass, several yellow perch and sticklebacks; 23 tags left in last lot (C750455) will be used for future Marymoor Taggings.
5/21/03	Madison Park Webster Point Gasworks Park	None	Purse Seine (1 Set Each Location)	0	0	0	0	0	0	NA	NONE		Purse seine captured primarily wild sockeye, with some coho at the two LW sites. Only 1 Chinook (Age 1+, captured at Webster). No tagging was performed due to the absence of Chinook.
5/27/03	Webster Point	Webster Point	Purse Seine (7 Sets total)	272	272	0	0	237	35	12.9	C750458 C750408 C750409 C750458	FAG03147.WEB	First 4 sets (1 at Madison Park and 3 just north of Webster Point captured no Chinook, only sockeye and coho. Last three sets just south of Webster Pt. Captured approx. 370 Chinook (40, 180, and 150 respectively). We tagged 273 Chinook before high stress levels from handling in the seine net caused us to stop and release them. There were approximately post-tagging mortalities for which were unable to recover the tags. The 87 tags left in last two lots (C750409 and C750457) will be used for future Webster Point Taggings.
5/28/03	Gasworks Park	Gasworks Park	Purse Seine (5 Sets total)	199	199	0	0	199	0	0.0	C750403 C750405 C750406	FAG03148.LUN	5 purse seine sets captured from 15 to 85 Chinook per set, for a total of 199 fish tagged. Catch was primarily wild sockeye and coho with approximately percent Chinook. Ninety five tags left in last lot (C750406) will be used for future Gasworks Taggings.
5/30/03	Kenmore	Kenmore	Beach Seine (2 sets)	410	410	0	0	410	0	0.0	C750430 C750445 C750456 C750404 C750407	FAG03150.KMB	2 beach seine sets each netted approximately 300 to 500 Chinook per set. Catch was >95 percent Chinook (predominately hatchery released) with a few chum, coho, perch, pike minnows, peamouth chub, and cutthroat. River temp was 17.5 degrees C, but fish handled well with no post tagging morts. Used remaining 90 tags (C750445) from previous visit from first visit. 78 tags left in last lot (C750407) will be used for future Kenmore taggings.
6/3/03	Marymoor Park	Marymoor Park	Beach Seine (4 sets)	400	400	0	0	397	3	0.8	C750431 C750432 C750433 C750434	FAG03154.MMB	4 beach seine sets netted approximately 450 Chinook total. Catch was >95 percent Chinook (predominately hatchery released. River temp was 19 degrees C on previous evening and was 16 degrees C during morning of tagging. Fish handled fairly well, and there were 3 post- tagging morts seen during fish release (1 was recaptured and x'ed out). Used all tubes of tags.
6/4/03	Webster Point	Madison Park	Purse Seine (4 sets total for day)	296	296	0	0	296	0	0.0	C750437 C750435 C750436	FAG03155.MDP	5 purse seine sets for the day netted approximately 500 Chinook total. Water temp in lake was 18 degrees C. Fish handled well, with no post tagging morts. Used all tags in the three vials.

Table A-2. Summary of tagging operations by date and location in the LWSC, Lake Washington, and the Sammamish River, 2003 Lake Washington PIT Tagging study.

Date	Capture Location	Release Location	Method of Wild Fish Capture	Total Number of Fish Tagged	Number of River Run Chinook Tagged	Number of Hatchery Transferred Chinook Tagged	Number of Other Salmon Species Tagged	Live Tagged Fish Successfully Released	Post Tagging Morts	Mortality Percentage	Tag Lot Numbers	File Names	Comments
6/4/03	Webster Point	East of Montlake Cut (next to UW shellhouse)	Purse Seine (4 sets total for day)	203	203	0	0	193	10	4.9	C762890 C750438 C750439	FAG03155.MEN	5 purse seine sets netted approximately 500 Chinook total. Water temp in lake was 18 degrees C. Fish handled O.K, but there were 10 morts discovered during release, which were not recovered. Vial C750439 has 96 tags remaining, which will be used at next Montlake Cut release.
6/5/03	Gasworks Park	West End of Fremont Cut	Purse Seine (5 sets total for day)	199	199	0	0	193	6	3.0	C762891 C762892	FAG03156.MLS FAG03156.MLN	5 purse seine sets (total for both Freemont cut and Gasworks releases) captured from 30 to 150 Chinook per set. A total of 199 fish were tagged for release at the west end of the Fremont Cut. Of these, 92 were released on the south side of the cut (adjacent to Metro Lab; FAG03156.MLS) and 107 were released on the north side of the ship canal (across from Metro Lab; FAG03156.MLN). There were 3 morts observed at each release site which could not be recovered. Used all tags in both vials for this release.
6/5/03	Gasworks Park	Gasworks Park	Purse Seine (5 sets total for day)	249	249	0	0	237	12	4.8	C750406 C762893 C762895	FAG03156.LUN	5 purse seine sets (total for both Freemont cut and Gasworks releases) captured from 30 to 150 Chinook per set. A total of 249 fish were tagged for release at the seine site south of point at Gasworks Park. Of the 249 fish released, 12 morts were observed which could not be recovered. IN addition, we saved out about 40 Chinook (over 100 mm) for use by Lynn McComas for acoustic tagging, as well as several larger (>125mm) coho for the same purposes. Used remaining 95 tags from vial C750406, left over from previous (5/28/03) Gasworks release. Used all tags in lot C762893. Used about 58 tags from last lot (C762895), with remaining 42 tags to be used in subsequent Gasworks released.
6/11/03	Gasworks Park	West End of Fremont Cut	Purse Seine (7 sets total for day)	200	200	0	0	196	4	2.0	C762896 C762894	FAG03162.MLN FAG03162.MLS	7 purse seine sets (total for both Freemont cut and Gasworks releases) captured from 2 to 150 Chinook per set. A total of 203 fish were tagged for release at the west end of the Fremont Cut. One hundred and fifteen Chinook released at south side of cut (by Metro Lab; FAG03162.MLS) with 3 morts observed (not recaptured). Eighty five fish were released at the north side of the cut (FAG03162.MLN; 1 mort observed). In addition, we saved out about 38 Chinook (over 100 mm) for use by Lynn McComas for acoustic tagging, as well as about 19 larger (>125mm) coho for the same purposes. Used all vial C762896 for the south side releases. Used about 17 tags from lot C762894 for south side releases and remainder for north side releases.
6/11/03	Gasworks Park	Gasworks Park	Purse Seine (7 sets total for day)	271	271	0	0	270	1	0.4	C762895 C762897 C762898 C762899	FAG03162.LUN FAG03162.LUS	7 purse seine sets (total for both Freemont cut and Gasworks releases) captured from 2 to 150 Chinook per set. A total of 270 fish were tagged for release near the seining site at Gasworks Park. At south side of release (near patch of trees and houseboats) 150 Chinook were released (FAG03162.LUS) with 1 mort observed (not recaptured). One hundred and twenty one fish were released at the north side of the seining site just south of the Park with no morts observed (FAG03162.LUN). Used remaining 42 tags from 6/5 tagging (Vial C762895) for the south side releases, as well as all of Vial C762897. Used all tags from Vial C762898 and about 20 tags from lot C762899 for north side releases.
6/12/03	Webster Point	Webster Point	Purse Seine (4 sets total for day)	23	23	0	0	23	0	0.0	Used Tags from Columbia River	FAG03163.WEB	Four seines yielded only 23 Chinook. 1st set = 13 Chinook, 2nd Set = 10 Chinook, and sets 3 and 4 = no Chinook. Water temp was 19 degrees Celsius. Did not make any further sets due to lack of fish and high water temperatures.
6/25/03	Kenmore	Kenmore	Beach Seine (4 sets)	0	0	0	0	0	0	NA	None	None	Four seines yielded only 10 Chinook. Water temp was 17 degrees Celsius. Did not make any further sets due to lack of fish and high water temperatures.

APPENDIX B

2003 PIT Tagging Data
Release and Detection Summary Tables

Table B-1. Summary of tagging numbers, 2003 PIT tag study.

			Numbers Released						
			Chinook		Coho		Sockeye	Steelhead	
Release Location	**Date**	**Time**	**Hatchery**	**Natural**	**Hatchery**	**Natural**	**Natural**	**Natural**	**TAGGING FILE**
Issaquah Hatchery	5/19/03	10:00	992	0	0	0	0	0	csm03105.I01
Bear Creek	4/29/03	13:00	0	0	0	347	0	0	CSM03119.FB1
	4/30/03	12:00	0	0	0	240	0	0	CSM03120.FB1
	5/1/03	12:30	0	4	0	157	0	0	CSM03121.FB1
	5/2/03	12:00	0	21	0	250	0	0	CSM03122.FB1
	5/5/03	13:00	0	64	0	205	0	0	CSM03125.FB1
	5/6/03	12:30	0	31	0	100	0	0	CSM03126.FB1
	5/7/03	13:00	0	65	0	100	0	0	CSM03127.FB1
	5/8/03	13:00	0	71	0	100	0	0	CSM03128.FB1
	5/9/03	13:00	0	131	0	100	0	0	CSM03129.FB1
	5/13/03	13:00	0	74	0	95	0	0	CSM03133.FB1
	5/14/03	13:00	0	59	0	100	0	0	CSM03134.FB1
	5/15/03	13:00	0	67	0	100	0	0	CSM03135.FB1
	5/16/03	15:00	0	172	0	100	0	0	CSM03136.FB1
	5/17/03	12:00	0	100	0	0	0	0	CSM03137.FB1
	5/19/03	8:30	0	100	0	0	0	0	CSM03139.FB1
	5/20/03	12:00	0	149	0	50	0	0	CSM03140.FB1
	5/21/03	9:00	0	146	0	0	0	0	CSM03141.FB1
	5/22/03	10:00	0	128	0	0	0	0	CSM03142.FB1
	5/23/03	8:30	0	32	0	0	0	0	CSM03143.FB1
	5/27/03	8:00	0	50	0	0	0	0	CSM03147.FB1
	5/28/03	8:00	0	43	0	0	0	0	CSM03148.FB1
	5/29/03	8:00	0	40	0	0	0	0	CSM03149.FB1
	5/30/03	9:00	0	156	0	0	0	0	CSM03150.FB1
	6/2/03	8:00	0	63	0	0	0	0	CSM03153.FB1
	6/3/03	8:00	0	40	0	0	0	0	CSM03154.FB1
	6/4/03	8:00	0	50	0	0	0	0	CSM03155.FB1
	6/5/03	8:00	0	50	0	0	0	0	CSM03156.FB1
	6/6/03	8:00	0	39	0	0	0	0	CSM03157.FB1
	6/9/03	7:30	0	33	0	0	0	0	CSM03160.FB1
	6/10/03	7:30	0	15	0	0	0	0	CSM03161.FB1
	6/11/03	7:30	0	34	0	0	0	0	CSM03162.FB1
	6/12/03	8:00	0	54	0	0	0	0	CSM03163.FB1
	6/13/03	7:30	0	18	0	0	0	0	CSM03164.FB1
	6/16/03	8:00	0	41	0	0	0	0	CSM03167.FB1
	6/17/03	7:30	0	29	0	0	0	0	CSM03168.FB1
	6/18/03	7:30	0	26	0	0	0	0	CSM03169.FB1

Table B-1. Summary of tagging numbers, 2003 PIT tag study.

			Numbers Released						
Release			**Chinook**		**Coho**		**Sockeye**	**Steelhead**	
Location	**Date**	**Time**	**Hatchery**	**Natural**	**Hatchery**	**Natural**	**Natural**	**Natural**	**TAGGING FILE**
Issaquah Hatchery	5/19/03	10:00	992	0	0	0	0	0	csm03105.I01
	6/20/03	7:45	0	26	0	0	0	0	CSM03171.FB1
	6/23/03	8:00	0	20	0	0	0	0	CSM03174.FB1
	6/25/03	9:30	0	16	0	0	0	0	CSM03176.FB1
	6/27/03	7:30	0	18	0	0	0	0	CSM03178.FB1
	6/30/03	7:30	0	24	0	0	0	0	CSM03181.FB1
	7/2/03	7:00	0	6	0	0	0	0	CSM03183.FB1
Cedar River	4/29/03	8:00	0	0	0	50	0	0	CSM03119.FC1
	4/30/03	8:30	0	0	0	102	0	0	CSM03120.FC1
	5/1/03	8:00	0	17	0	62	0	0	CSM03121.FC1
	5/2/03	8:00	0	18	0	84	0	0	CSM03122.FC1
	5/5/03	9:30	0	24	0	61	0	0	CSM03125.FC1
	5/6/03	8:00	0	19	0	150	0	0	CSM03126.FC1
	5/7/03	8:30	0	34	0	94	0	0	CSM03127.FC1
	5/8/03	10:00	0	0	0	46	0	0	CSM03128.FC1
	5/9/03	8:30	0	27	0	99	0	0	CSM03129.FC1
	5/13/03	8:00	0	21	0	37	1	0	CSM03133.FC1
	5/15/03	6:30	0	18	0	45	0	0	CSM03134.FC1
	5/16/03	10:00	0	110	0	155	0	2	CSM03136.FC1
	5/17/03	8:00	0	16	0	42	0	0	CSM03137.FC1
	5/19/03	11:30	0	67	0	0	0	0	CSM03139.FC1
	5/20/03	8:00	0	39	0	0	0	0	CSM03140.FC1
	5/21/03	11:00	0	22	0	0	0	0	CSM03141.FC1
	5/22/03	8:00	0	21	0	0	0	0	CSM03142.FC1
	5/23/03	8:00	0	42	0	0	0	0	CSM03143.FC1
	5/27/03	10:00	0	42	0	0	0	0	CSM03147.FC1
	5/28/03	11:00	0	40	0	0	0	0	CSM03148.FC1
	5/29/03	10:00	0	43	0	0	0	0	CSM03149.FC1
	5/30/03	10:30	0	35	0	0	0	0	CSM03150.FC1
	6/2/03	9:30	0	56	0	0	0	0	CSM03153.FC1
	6/3/03	10:00	0	100	0	0	0	2	CSM03154.FC1
	6/4/03	11:00	1	56	0	0	0	0	CSM03155.FC1
	6/5/03	11:00	5	93	0	0	0	0	CSM03156.FC1
	6/6/03	10:00	0	50	0	0	0	0	CSM03157.FC1
	6/9/03	9:30	0	100	0	0	0	0	CSM03160.FC1
	6/10/03	9:00	0	59	0	0	0	0	CSM03161.FC1
	6/11/03	10:30	0	79	0	0	0	0	CSM03162.FC1

Table B-1. Summary of tagging numbers, 2003 PIT tag study.

Release Location	Date	Time	Numbers Released: Chinook Hatchery	Chinook Natural	Coho Hatchery	Coho Natural	Sockeye Natural	Steelhead Natural	TAGGING FILE
Issaquah Hatchery	5/19/03	10:00	992	0	0	0	0	0	csm03105.I01
	6/12/03	11:00	0	94	0	0	0	0	CSM03163.FC1
	6/13/03	9:30	0	68	0	0	0	1	CSM03164.FC1
	6/16/03	10:00	0	36	0	0	0	0	CSM03167.FC1
	6/16/03	9:30	0	51	0	0	0	0	CSM03167.FC2
	6/17/03	9:00	0	23	0	0	0	0	CSM03168.FC1
	6/18/03	10:00	0	39	0	0	0	0	CSM03169.FC1
	6/20/03	9:30	0	69	0	0	0	0	CSM03171.FC1
	6/23/03	10:00	0	9	0	0	0	0	CSM03174.FC1
	6/25/03	8:00	0	16	0	0	0	0	CSM03176.FC1
	6/25/03	8:00	0	37	0	0	0	0	CSM03176.FC2
	6/27/03	9:00	0	11	0	0	0	0	CSM03178.FC1
	6/30/03	8:30	0	5	0	0	0	0	CSM03181.FC1
	7/2/03	9:06	0	20	0	0	0	0	CSM03183.FC1
Marymoor Park	5/6/03	7:30	0	2	0	0	0	0	FAG03126.MMB
	5/6/03	11:00	375	0	0	0	0	0	FAG03126.MMH
	5/20/03	7:30	387	1	0	0	0	0	FAG03140.MMH
	6/3/03	9:00	392	7	0	0	0	0	FAG03154.MMB
Kenmore	5/13/03	11:00	0	0	0	0	0	0	FAG03133.KMB
	5/13/03	11:00	351	0	0	0	0	0	FAG03133.KMH
	5/30/03	7:30	402	7	0	0	0	0	FAG03150.KMB
Gene Coulon Park	5/8/03	10:00	0	165	0	0	0	0	CSM03128.KLN
Madison Park	6/4/03	12:00	291	5	0	0	0	0	FAG03155.MDP
Magnuson Park	5/14/03	14:00	0	0	0	0	335	0	FAG03134.WEB
Webster Point	5/27/03	17:30	239	32	0	0	0	0	FAG03147.WEB
	6/12/03	14:00	20	3	0	0	0	0	FAG03163.WEB
Montlake Cut, East	6/4/03	15:00	199	4	0	0	0	0	FAG03155.MEN
Lake Union (Gasworks), North Shore	5/28/03	15:00	154	45	0	0	0	0	FAG03148.LUN
	6/5/03	15:00	237	12	0	0	0	0	FAG03156.LUN
	6/11/03	16:00	115	5	0	0	0	0	FAG03162.LUN
Lake Union (Gasworks), South Shore	6/11/03	14:00	140	10	0	0	0	0	FAG03162.LUS
Metro Lab, North Shore	6/5/03	13:30	105	2	0	0	0	0	FAG03156.MLN
	6/11/03	12:00	77	8	0	0	0	0	FAG03162.MLN
Metro Lab, South Shore	6/5/03	11:00	88	4	0	0	0	0	FAG03156.MLS
	6/11/03	12:00	108	7	0	0	0	0	FAG03162.MLS

Table B-2. Summary of Chinook salmon recapture numbers, 2003 PIT tag study.

	Release		Number of Fish Detected at Locks in Each Flume							
			Hatchery Produced				Naturally Produced			
Tagging File	**Location**	**Date**	**4A**	**4B**	**5C**	**5B**	**4A**	**4B**	**5C**	**5B**
csm03105.I01	Issaquah Hatchery	5/19/03	0	209	21	6	0	0	0	0
CSM03119.FB1	Bear Creek	4/29/03	0	0	0	0	0	0	0	0
CSM03120.FB1		4/30/03	0	0	0	0	0	0	0	0
CSM03121.FB1		5/1/03	0	0	0	0	0	2	0	0
CSM03122.FB1		5/2/03	0	0	0	0	0	2	3	0
CSM03125.FB1		5/5/03	0	0	0	0	0	11	4	7
CSM03126.FB1		5/6/03	0	0	0	0	0	7	1	1
CSM03127.FB1		5/7/03	0	0	0	0	0	9	11	5
CSM03128.FB1		5/8/03	0	0	0	0	0	13	7	9
CSM03129.FB1		5/9/03	0	0	0	0	0	39	14	9
CSM03133.FB1		5/13/03	0	0	0	0	0	22	9	4
CSM03134.FB1		5/14/03	0	0	0	0	0	14	3	5
CSM03135.FB1		5/15/03	0	0	0	0	0	22	9	5
CSM03136.FB1		5/16/03	0	0	0	0	0	56	15	8
CSM03137.FB1		5/17/03	0	0	0	0	0	32	6	1
CSM03139.FB1		5/19/03	0	0	0	0	1	35	3	1
CSM03140.FB1		5/20/03	0	0	0	0	0	46	12	3
CSM03141.FB1		5/21/03	0	0	0	0	0	35	4	9
CSM03142.FB1		5/22/03	0	0	0	0	0	50	5	0
CSM03143.FB1		5/23/03	0	0	0	0	0	14	1	0
CSM03147.FB1		5/27/03	0	0	0	0	0	10	2	0
CSM03148.FB1		5/28/03	0	0	0	0	0	15	0	2
CSM03149.FB1		5/29/03	0	0	0	0	0	6	1	0
CSM03150.FB1		5/30/03	0	0	0	0	0	36	1	0
CSM03153.FB1		6/2/03	0	0	0	0	0	7	0	0
CSM03154.FB1		6/3/03	0	0	0	0	0	8	0	0
CSM03155.FB1		6/4/03	0	0	0	0	0	1	0	0
CSM03156.FB1		6/5/03	0	0	0	0	0	4	0	0
CSM03157.FB1		6/6/03	0	0	0	0	0	2	0	0
CSM03160.FB1		6/9/03	0	0	0	0	0	1	0	0
CSM03161.FB1		6/10/03	0	0	0	0	0	0	0	0
CSM03162.FB1		6/11/03	0	0	0	0	0	1	0	0
CSM03163.FB1		6/12/03	0	0	0	0	0	1	0	0
CSM03164.FB1		6/13/03	0	0	0	0	0	0	0	0
CSM03167.FB1		6/16/03	0	0	0	0	0	0	0	0
CSM03168.FB1		6/17/03	0	0	0	0	0	0	0	0
CSM03169.FB1		6/18/03	0	0	0	0	0	0	0	0
CSM03171.FB1		6/20/03	0	0	0	0	0	0	0	0

Table B-2. Summary of Chinook salmon recapture numbers, 2003 PIT tag study.

			Number of Fish Detected at Locks in Each Flume							
	Release		Hatchery Produced				Naturally Produced			
Tagging File	**Location**	**Date**	**4A**	**4B**	**5C**	**5B**	**4A**	**4B**	**5C**	**5B**
CSM03174.FB1		6/23/03	0	0	0	0	0	0	0	0
CSM03176.FB1		6/25/03	0	0	0	0	0	0	0	0
CSM03178.FB1		6/27/03	0	0	0	0	0	0	0	0
CSM03181.FB1		6/30/03	0	0	0	0	0	0	0	0
CSM03183.FB1		7/2/03	0	0	0	0	0	0	0	0
CSM03119.FC1	Cedar River	4/29/03	0	0	0	0	0	0	0	0
CSM03120.FC1		4/30/03	0	0	0	0	0	0	0	0
CSM03121.FC1		5/1/03	0	0	0	0	0	4	1	3
CSM03122.FC1		5/2/03	0	0	0	0	0	7	2	1
CSM03125.FC1		5/5/03	0	0	0	0	0	5	1	3
CSM03126.FC1		5/6/03	0	0	0	0	0	4	3	1
CSM03127.FC1		5/7/03	0	0	0	0	0	7	6	3
CSM03128.FC1		5/8/03	0	0	0	0	0	0	0	0
CSM03129.FC1		5/9/03	0	0	0	0	0	6	3	1
CSM03133.FC1		5/13/03	0	0	0	0	0	6	4	0
CSM03134.FC1		5/15/03	0	0	0	0	0	7	3	1
CSM03136.FC1		5/16/03	0	0	0	0	0	30	5	3
CSM03137.FC1		5/17/03	0	0	0	0	0	8	0	2
CSM03139.FC1		5/19/03	0	0	0	0	0	15	6	4
CSM03140.FC1		5/20/03	0	0	0	0	0	13	1	1
CSM03141.FC1		5/21/03	0	0	0	0	0	9	0	0
CSM03142.FC1		5/22/03	0	0	0	0	0	9	2	1
CSM03143.FC1		5/23/03	0	0	0	0	0	9	3	2
CSM03147.FC1		5/27/03	0	0	0	0	0	12	0	0
CSM03148.FC1		5/28/03	0	0	0	0	0	15	0	2
CSM03149.FC1		5/29/03	0	0	0	0	0	23	1	0
CSM03150.FC1		5/30/03	0	0	0	0	0	17	0	0
CSM03153.FC1		6/2/03	0	0	0	0	0	23	0	0
CSM03154.FC1		6/3/03	0	0	0	0	1	38	1	0
CSM03155.FC1		6/4/03	0	1	0	0	0	15	1	0
CSM03156.FC1		6/5/03	0	0	0	0	1	28	2	2
CSM03157.FC1		6/6/03	0	0	0	0	0	10	1	1
CSM03160.FC1		6/9/03	0	0	0	0	0	9	1	3
CSM03161.FC1		6/10/03	0	0	0	0	1	7	2	0
CSM03162.FC1		6/11/03	0	0	0	0	0	6	1	1
CSM03163.FC1		6/12/03	0	0	0	0	0	4	1	1
CSM03164.FC1		6/13/03	0	0	0	0	0	8	1	0
CSM03167.FC1		6/16/03	0	0	0	0	0	0	0	0

Table B-2. Summary of Chinook salmon recapture numbers, 2003 PIT tag study.

			Number of Fish Detected at Locks in Each Flume							
	Release		Hatchery Produced				Naturally Produced			
Tagging File	**Location**	**Date**	**4A**	**4B**	**5C**	**5B**	**4A**	**4B**	**5C**	**5B**
CSM03167.FC2		6/16/03	0	0	0	0	0	0	0	0
CSM03168.FC1		6/17/03	0	0	0	0	0	1	0	0
CSM03169.FC1		6/18/03	0	0	0	0	0	0	0	0
CSM03171.FC1		6/20/03	0	0	0	0	0	3	0	0
CSM03174.FC1		6/23/03	0	0	0	0	0	0	0	0
CSM03176.FC1		6/25/03	0	0	0	0	0	0	0	0
CSM03176.FC2		6/25/03	0	0	0	0	0	0	0	0
CSM03178.FC1		6/27/03	0	0	0	0	0	0	0	0
CSM03181.FC1		6/30/03	0	0	0	0	0	0	0	0
CSM03183.FC1		7/2/03	0	0	0	0	0	0	0	0
FAG03126.MMB	Marymoor Park	5/6/03	0	0	0	0	0	0	0	0
FAG03126.MMH		5/6/03	0	78	44	21	0	0	0	0
FAG03140.MMH		5/20/03	0	102	9	7	0	0	0	0
FAG03154.MMB		6/3/03	1	51	3	2	0	1	0	0
FAG03133.KMB	Kenmore	5/13/03	0	0	0	0	0	0	0	0
FAG03133.KMH		5/13/03	0	95	38	28	0	0	0	0
FAG03150.KMB		5/30/03	0	137	4	0	0	5	0	0
CSM03128.KLN	Gene Coulon Park	5/8/03	0	0	0	0	0	5	6	2
FAG03155.MDP	Madison Park	6/4/03	1	20	0	1	0	0	0	0
FAG03147.WEB	Webster Point	5/27/03	0	5	1	0	0	0	0	0
FAG03163.WEB		6/12/03	0	0	0	0	0	0	0	0
FAG03155.MEN	Montlake Cut, East	6/4/03	0	24	0	0	0	1	0	0
FAG03148.LUN	Lake Union (Gasworks), North Shore	5/28/03	0	21	12	5	0	5	2	2
FAG03156.LUN		6/5/03	0	22	1	0	0	1	0	0
FAG03162.LUN		6/11/03	0	6	0	0	0	0	0	0
FAG03162.LUS	Lake Union (Gasworks), South Shore	6/11/03	0	17	0	0	0	2	0	0
FAG03156.MLN	Metro Lab, North Shore	6/5/03	0	29	0	0	0	1	0	0
FAG03162.MLN		6/11/03	0	9	0	0	0	0	0	0
FAG03156.MLS	Metro Lab, South Shore	6/5/03	0	15	1	0	0	0	0	0
FAG03162.MLS		6/11/03	0	14	0	1	0	1	0	0

Table B-3. Summary of coho salmon recapture numbers, 2003 PIT tag study.

			Number of Fish Detected at Locks in Each Flume							
	Release		Hatchery Produced				Naturally Produced			
Tagging File	**Location**	**Date**	**4A**	**4B**	**5C**	**5B**	**4A**	**4B**	**5C**	**5B**
CSM03119.FB1	Bear Creek	4/29/03	0	0	0	0	0	29	87	95
CSM03120.FB1		4/30/03	0	0	0	0	0	15	70	87
CSM03121.FB1		5/1/03	0	0	0	0	0	12	46	54
CSM03122.FB1		5/2/03	0	0	0	0	0	18	68	78
CSM03125.FB1		5/5/03	0	0	0	0	0	14	63	49
CSM03126.FB1		5/6/03	0	0	0	0	0	5	26	29
CSM03127.FB1		5/7/03	0	0	0	0	0	4	20	27
CSM03128.FB1		5/8/03	0	0	0	0	1	3	26	26
CSM03129.FB1		5/9/03	0	0	0	0	0	2	40	18
CSM03133.FB1		5/13/03	0	0	0	0	0	8	21	12
CSM03134.FB1		5/14/03	0	0	0	0	0	6	30	17
CSM03135.FB1		5/15/03	0	0	0	0	0	7	22	25
CSM03136.FB1		5/16/03	0	0	0	0	0	6	32	15
CSM03137.FB1		5/17/03	0	0	0	0	0	0	0	0
CSM03139.FB1		5/19/03	0	0	0	0	0	0	0	0
CSM03140.FB1		5/20/03	0	0	0	0	0	4	14	3
CSM03141.FB1		5/21/03	0	0	0	0	0	0	0	0
CSM03142.FB1		5/22/03	0	0	0	0	0	0	0	0
CSM03143.FB1		5/23/03	0	0	0	0	0	0	0	0
CSM03147.FB1		5/27/03	0	0	0	0	0	0	0	0
CSM03148.FB1		5/28/03	0	0	0	0	0	0	0	0
CSM03149.FB1		5/29/03	0	0	0	0	0	0	0	0
CSM03150.FB1		5/30/03	0	0	0	0	0	0	0	0
CSM03153.FB1		6/2/03	0	0	0	0	0	0	0	0
CSM03154.FB1		6/3/03	0	0	0	0	0	0	0	0
CSM03155.FB1		6/4/03	0	0	0	0	0	0	0	0
CSM03156.FB1		6/5/03	0	0	0	0	0	0	0	0
CSM03157.FB1		6/6/03	0	0	0	0	0	0	0	0
CSM03160.FB1		6/9/03	0	0	0	0	0	0	0	0
CSM03161.FB1		6/10/03	0	0	0	0	0	0	0	0
CSM03162.FB1		6/11/03	0	0	0	0	0	0	0	0
CSM03163.FB1		6/12/03	0	0	0	0	0	0	0	0
CSM03164.FB1		6/13/03	0	0	0	0	0	0	0	0
CSM03167.FB1		6/16/03	0	0	0	0	0	0	0	0
CSM03168.FB1		6/17/03	0	0	0	0	0	0	0	0
CSM03169.FB1		6/18/03	0	0	0	0	0	0	0	0
CSM03171.FB1		6/20/03	0	0	0	0	0	0	0	0
CSM03174.FB1		6/23/03	0	0	0	0	0	0	0	0
CSM03176.FB1		6/25/03	0	0	0	0	0	0	0	0
CSM03178.FB1		6/27/03	0	0	0	0	0	0	0	0
CSM03181.FB1		6/30/03	0	0	0	0	0	0	0	0
CSM03183.FB1		7/2/03	0	0	0	0	0	0	0	0

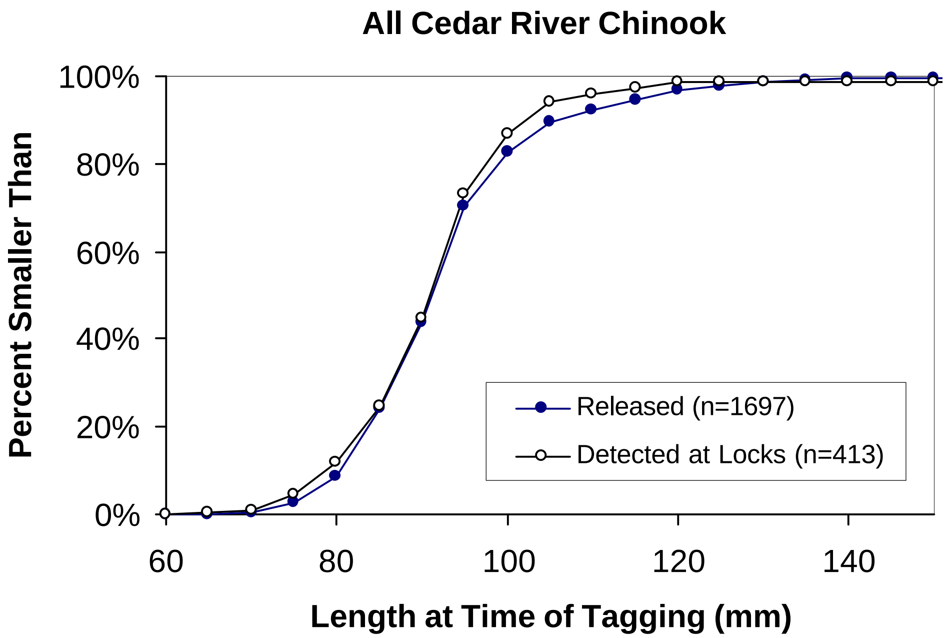
Table B-3. Summary of coho salmon recapture numbers, 2003 PIT tag study.

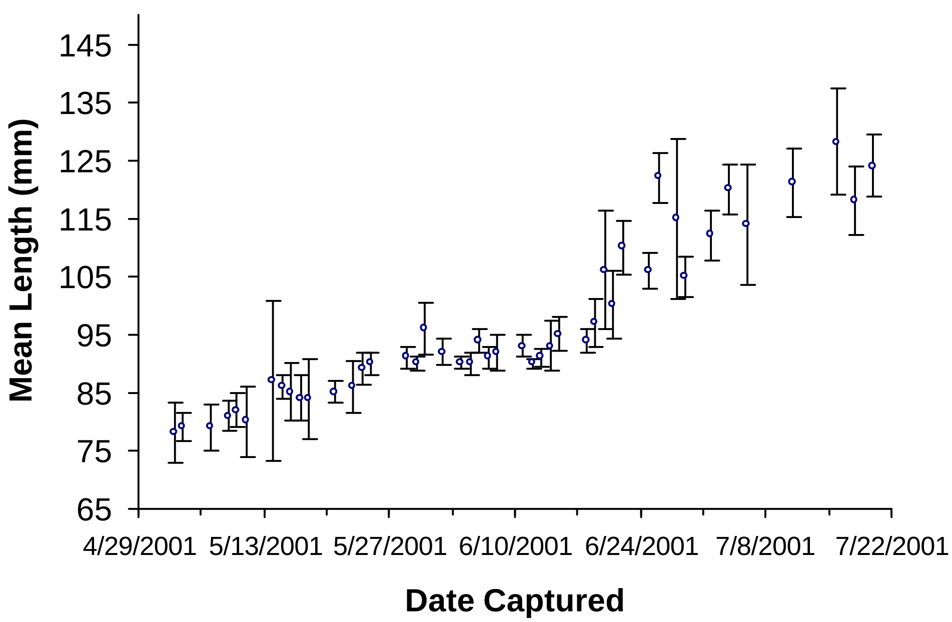
			Number of Fish Detected at Locks in Each Flume							
	Release		Hatchery Produced				Naturally Produced			
Tagging File	**Location**	**Date**	**4A**	**4B**	**5C**	**5B**	**4A**	**4B**	**5C**	**5B**
CSM03119.FC1	Cedar River	4/29/03	0	0	0	0	0	3	14	12
CSM03120.FC1		4/30/03	0	0	0	0	0	7	21	29
CSM03121.FC1		5/1/03	0	0	0	0	0	3	7	15
CSM03122.FC1		5/2/03	0	0	0	0	0	5	25	21
CSM03125.FC1		5/5/03	0	0	0	0	0	6	17	15
CSM03126.FC1		5/6/03	0	0	0	0	0	6	45	32
CSM03127.FC1		5/7/03	0	0	0	0	0	4	25	24
CSM03128.FC1		5/8/03	0	0	0	0	0	6	12	8
CSM03129.FC1		5/9/03	0	0	0	0	0	7	21	19
CSM03133.FC1		5/13/03	0	0	0	0	0	3	8	11
CSM03134.FC1		5/15/03	0	0	0	0	0	3	11	11
CSM03136.FC1		5/16/03	0	0	0	0	0	22	36	20
CSM03137.FC1		5/17/03	0	0	0	0	0	4	12	5
CSM03139.FC1		5/19/03	0	0	0	0	0	0	0	0
CSM03140.FC1		5/20/03	0	0	0	0	0	0	0	0
CSM03141.FC1		5/21/03	0	0	0	0	0	0	0	0
CSM03142.FC1		5/22/03	0	0	0	0	0	0	0	0
CSM03143.FC1		5/23/03	0	0	0	0	0	0	0	0
CSM03147.FC1		5/27/03	0	0	0	0	0	0	0	0
CSM03148.FC1		5/28/03	0	0	0	0	0	0	0	0
CSM03149.FC1		5/29/03	0	0	0	0	0	0	0	0
CSM03150.FC1		5/30/03	0	0	0	0	0	0	0	0
CSM03153.FC1		6/2/03	0	0	0	0	0	0	0	0
CSM03154.FC1		6/3/03	0	0	0	0	0	0	0	0
CSM03155.FC1		6/4/03	0	0	0	0	0	0	0	0
CSM03156.FC1		6/5/03	0	0	0	0	0	0	0	0
CSM03157.FC1		6/6/03	0	0	0	0	0	0	0	0
CSM03160.FC1		6/9/03	0	0	0	0	0	0	0	0
CSM03161.FC1		6/10/03	0	0	0	0	0	0	0	0
CSM03162.FC1		6/11/03	0	0	0	0	0	0	0	0
CSM03163.FC1		6/12/03	0	0	0	0	0	0	0	0
CSM03164.FC1		6/13/03	0	0	0	0	0	0	0	0
CSM03167.FC1		6/16/03	0	0	0	0	0	0	0	0
CSM03167.FC2		6/16/03	0	0	0	0	0	0	0	0
CSM03168.FC1		6/17/03	0	0	0	0	0	0	0	0
CSM03169.FC1		6/18/03	0	0	0	0	0	0	0	0
CSM03171.FC1		6/20/03	0	0	0	0	0	0	0	0
CSM03174.FC1		6/23/03	0	0	0	0	0	0	0	0
CSM03176.FC1		6/25/03	0	0	0	0	0	0	0	0
CSM03176.FC2		6/25/03	0	0	0	0	0	0	0	0
CSM03178.FC1		6/27/03	0	0	0	0	0	0	0	0
CSM03181.FC1		6/30/03	0	0	0	0	0	0	0	0
CSM03183.FC1		7/2/03	0	0	0	0	0	0	0	0

APPENDIX C

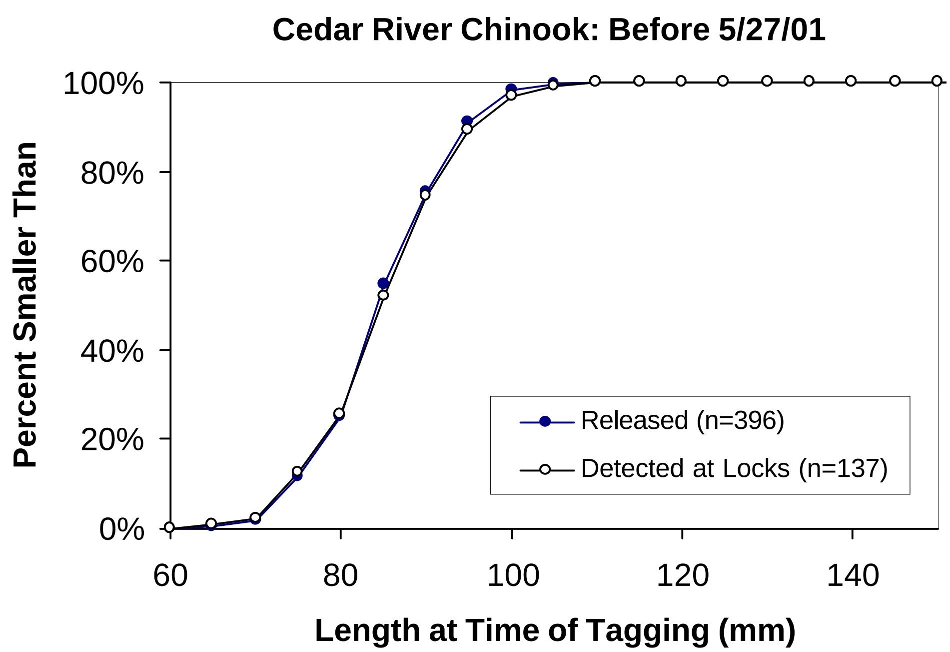
Errata for 2001 Report

The following graphs replace the graphs in Figure 3-17 of DeVries (2002):





The following graph replaces the top graph in Figure 3-18 of DeVries (2002):



This page missing in original report (DeVries 2002).

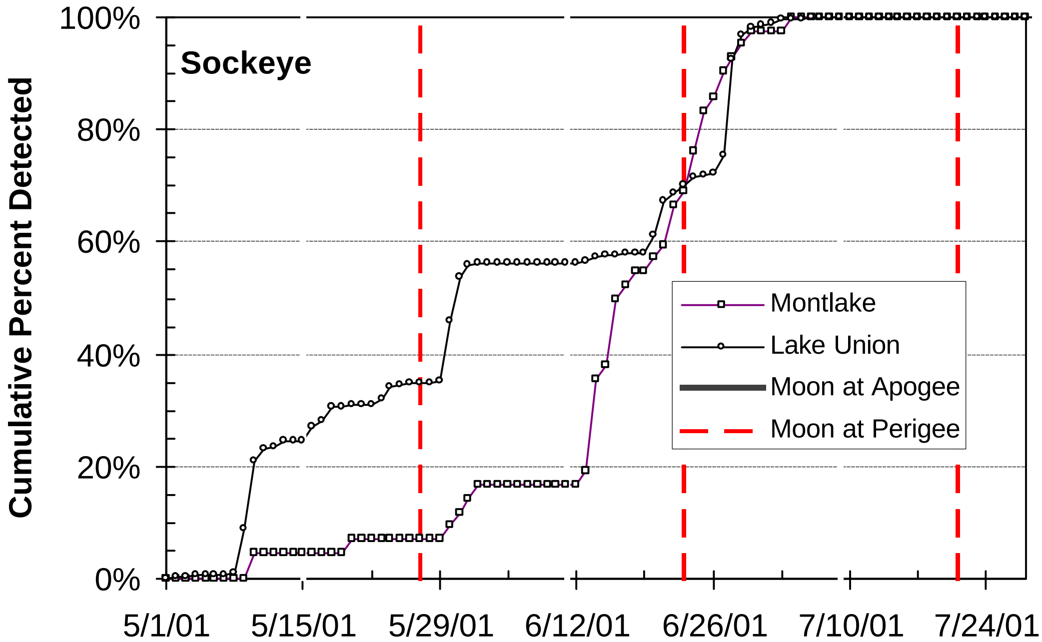


Figure 3-20. (continued) Cumulative frequency distributions of the numbers of PIT tagged juvenile chinook, coho, and sockeye salmon that were detected, as they passed the smolt flumes at the Locks, by date and release location, 2001 Lake Washington GI study. The dates when the moon was at apogee and perigee are indicated by the vertical lines.

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